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February 21, 2020

Norman W. Bernstein
Peter M. Racher
Third Site Trust
Via e-mail

Dear Mr. Bernstein:

Thank you for sending us your February 10, 2020 proposed sampling plan written by Geosyntec Consultants International, Inc. While McMillan-McGee Corporation (Mc^2) agrees with several aspects of the proposed sampling plan, we observed that it does not include any groundwater monitoring outside of the existing recovery well and monitoring well network within the DNAPL containment area. Mc^2 regards this omission as a serious data gap that needs to be addressed. Restricting groundwater sampling to the existing monitoring and recovery wells is problematic for the following reasons:

1. Existing monitoring and recovery wells have screens that extend to a maximum of 40 feet below ground surface (BGS), coincident with the bottom of the defined thermal treatment zone. Limiting groundwater sampling to these wells ignores potential contamination from deeper in the lower till;
2. The monitoring and recovery wells act as vertical conduits for groundwater flow. Since the volume in question is within a sheet pile-enclosed area of small dimensions, it is anticipated that groundwater flow is largely a matter of up-and-down movements of the water table. Such movements would preferentially move through the wells, since the resistance of flow through an open well is orders of magnitude less than flow through the soil matrix.[1] This condition means that a groundwater sample collected from a vertical interval within a monitoring well may not necessarily originate from that depth, and thus would likely be unrepresentative of conditions within the adjacent soil matrix;
3. All of the recovery and monitoring wells (except the 'Sump' well) have silt traps; these may have residual contamination unrepresentative of conditions within the neighboring soil matrix.

[1]Baptiste and Chapuis found hydraulic conductivity values for comparable well screens to be approximately 0.25 cm/sec, compared to soil hydraulic conductivities measured in the lower till measured at 0.000005684 cm/sec to 0.001386 cm/sec. See Baptiste and Chapuis, *What maximum permeability can be measured with a monitoring well?* Engineering Geology, Volume 184, 14 January 2015, pp. 111-118, and *DNAPL Containment Area, Supplemental Data Collection Report, Third Site Superfund Site, Zionsville, Indiana* (Environ, 2014).

For these reasons, Mc^2 has proposed conducting continuous vertical groundwater profiling to 46 feet BGS within the DNAPL containment area. This could be conducted using the Waterloo APS™, the Geoprobe® HPT-GWS, or the Geoprobe 1.75GW Profiler direct-push mounted tools.[2] Use of these tools would allow:

1. Sample collection to the proposed depth of 46 feet BGS, or deeper, if desired; and
2. Groundwater samples truly representative of the local soil matrix, unaffected by the potential for preferential groundwater flow or possible residual contamination.

Please refer to our January 10th, 2020 sampling plan for further details (attached for your reference).

Lower Till Contamination: Previous investigations in the DNAPL containment area suggest that contamination in the lower till is not fully vertically delineated. Generally, data collection was restricted to 37 feet BGS or less; however, the deepest data collected did not demonstrate uncontaminated conditions. For example, see the following results obtained from the lowermost data collection points at selected boreholes or wells during the 2014 DNAPL Area investigation[3]:

- Groundwater Samples from Continuous Multi-Channel Tubing Wells

Location	**Depth** (feet BGS)	**TVOCs Concentration** (µg/L)
CMT-1-7	34.5	122,174
CMT-2-7	35.0	10,351
CMT-3-7	33.0	1,940

- Membrane Interface Probe (MIP) results. Note that a response of 2.5×10^7 µV was correlated to DNAPL occurrence, so these results indicate very elevated groundwater concentrations.

Location	**Depth** (feet BGS)	**PID Response** (µV)
MIP-03.MHP	31.8	3.0×10^7
MIP-05.MHP	33.8	1.0×10^7
MIP-06.MHP	32.0	2.5×10^7
MIP-14.MHP	36.8	2.5×10^7
MIP-15.MHP	32.0	2.5×10^7

- Soil data results. Calculations performed by Environ indicate that a trichloroethylene soil threshold concentration of 1,623 mg/kg corresponds to a groundwater concentration of 638,000 µg/L. Under equilibrium conditions, this ratio of 393.1 µg/L per mg/kg should hold, allowing calculation of groundwater concentrations from soil data.

[redacted]

[2] See https://geoprobe.com/hpt-hydraulic-profiling-tool for more information.

[3] *DNAPL Containment Area, Supplemental Data Collection Report, Third Site Superfund Site, Zionsville, Indiana* (Environ, 2014).

Location	**Depth** (feet BGS)	**TCE Soil Concentration** (mg/kg)	**TCE Equivalent Groundwater Concentration** (µg/L)
TS-01	30.9	91.5	35,969
TS-02	31.5	30.7	12,068

While the above results are obviously selected data, they do indicate that the potential for contamination deeper than previously assessed is quite real, and demands further investigation before remedial efforts continue.

Lower Till Unit Hydraulic Conductivity: In previous correspondence, the Trust raised the possibility that the lower till unit's hydraulic conductivity is too low to allow obtaining a sample from a direct-push groundwater sampler. While Mc^2 is unaware of a direct measurement of the lower till unit hydraulic conductivity, it is noted that the grain-size distribution from the upper till (58.4% silt and clay, 41.6% sand and gravel) and the lower till (66.9% silt and clay, 33.1% sand and gravel) are similar. Rising-head slug tests completed in the upper till at piezometers STP-1 and STP-2 reported hydraulic conductivities of 5.684 E-06 cm/sec and 1.386 E-03 cm/sec, respectively, while HPT tool at location MIP-16.MHP reported hydraulic conductivities as high as approximately 1.411 E-02 cm/sec.[4] This suggests that hydraulic conductivities are sufficient to allow groundwater sampling in the lower till.

Additionally, groundwater samples have previously been collected from multiple-screen monitoring wells CMT-1, CMT-2, and CMT-3 from depth intervals within the lower till of 34.0-34.5, 34.5-35.0, and 32.5-33.0 feet BGS, respectively. This demonstrates that sufficient groundwater flow exists within the lower till to allow for groundwater sampling.[5]

Please feel free to contact us if you have any questions.

Sincerely,

David A. Rountree, P.E., P.Eng.
Chief Engineer
McMillan-McGee Corporation

Attachments (1)
Cc: Matthew Ohl, U.S. Environmental Protection Agency

[4] Environ, 2014.

[5] *Ibid.*

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Memorandum

To:	Norman W. Bernstein Peter M. Racher	Date:	January 10, 2020
From:	McMillan-McGee Corporation	Location:	Calgary

Re: Third Site Additional Sampling Plan

McMillan-McGee Corporation (Mc^2) has reviewed Geosyntec's recommendations in their December 20th, 2019 memorandum. We have based the following data collection plan based on our previous plans, Geosyntec's recommendations, and established site investigative techniques[1].

Note that Mc^2 does not recommend the use of Hydrasleeve samplers within existing site wells for groundwater monitoring. Use of existing wells restricts the contaminant concentration groundwater profile to the vertical range of these wells. Groundwater concentrations below the depth of existing monitoring and recovery wells are of particular interest in this situation. Furthermore, groundwater samples are collected by a vertical profiler tool within the saturated soil matrix of the site. This is likely more indicative of relevant site conditions than samples collected from a well spanning varying lithologies, since wells may serve as preferential vertical pathways and/or contaminant accumulation points.

Mc^2 proposes the following:

1. **Obtain twelve vertical groundwater concentration profiles.** Ten profiles are to be collected within a 2-foot radius of P-1, P-2, X-B3, X-C1, the Sump well, X-C3, X-C4, X-D3, X-D4, and X-E1. Two additional profiles are to be collected along the sheetpile wall adjacent to X-E2 and X-E3. These locations largely correspond to Geosyntec's recommendations, with the following exceptions:

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[1] See e.g., *An Introduction to Characterizing Sites Contaminated with DNAPL,* The Interstate Technology & Regulatory Council, 2003, and Kueper, Bernard H. and Davies, Kathryn L., *Assessment and Delineation of DNAPL Source Zones at Hazardous Waste Sites,* Ground Water Issue, USEPA 600-R-09-119, 2009.

  a. Eliminating a location near X-B4, since P-2 and X-B4 are within ~4 feet of each other;
  b. Adding a location near the Sump well;
  c. Moving locations near X-E2 and X-E3 towards the sheetpile wall, as location of interest.

  Mc^2 recommends a groundwater vertical profiler tool such as the Waterloo APS or BAT sampler (see technical information in Appendix A). Groundwater samples are collected at 3-foot intervals to 46 feet BGS. Each sample will be subjected to USEPA Method 8260 analysis.

2. **Collect continuous soil cores to 46 feet.** Two core locations are within 4 feet of P-1 two within four feet and P-2, and two locations are within 3 feet of the sheet pile wall. Refer to Appendix B for details. Additional locations would be selected based on the results of the vertical profiler tool results described above.

   These cores will be collected in accordance with Mc^2's hot soil sampling Job Safety Analysis (Appendix C). The cores will be screened via photoionization detector (PID) once cooled. Soil samples will be collected from the location of greatest PID response within each 5-foot section of soil core for laboratory analysis by USEPA method 8260. If soil cores are encountered with no PID response, the first such core will be sampled for USEPA method 8260 analysis, with subsequent such cores put into storage. Representative samples from the upper till, sand unit, and lower till will also be analyzed for triaxial intrinsic permeability at a geotechnical lab.

A map of the proposed sample locations is included in Appendix B. The map also shows proposed equipment movements to obtain access to the site well field. Mc^2 proposes to schedule this work as soon as possible, depending on driller and tooling availability, and pending agreement on funding of this work.

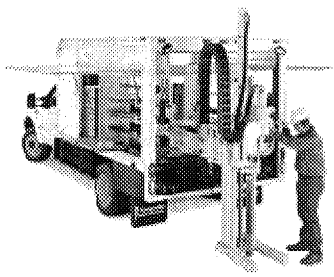
Appendix A

1. *Contaminated Site Clean-Up Information, Groundwater Samplers,* USEPA CLU-IN website, https://clu-in.org/characterization/technologies/dpgroundwater.cfm, retrieved November 28, 2019.
2. Excerpt from *Groundwater Sampling and Monitoring with Direct Push Technologies,* USEPA 540-R-04-005, 2005, pp. 9 through 14.
3. Torstensson, Bengt-Arne, *A New System for Ground Water Monitoring,* Ground Water Monitoring Review, Fall 1984.

U.S. EPA Contaminated Site Cleanup Information (CLU-IN)

Groundwater Samplers

Introduction



Percussion hammer direct-push system. Courtesy of Geoprope Systems.

Groundwater sampling with direct-push systems (DPS) has gained widespread acceptance in the environmental industry over the past decade because of the versatility, relatively low cost, and mobility of these systems. The two major classes of direct-push platforms are cone penetrometer testing (CPT) and percussion hammer systems. The distinction between these systems is that CPT advances the tool string by applying a hydraulic ram against the weight or mass of the vehicle alone, while percussion hammer units use a hammer to drive the tool string into the ground. These systems share the same principle of operation, similar tools, and a number of advantages and limitations. Some percussion hammer rigs also add a high-frequency vibration feature to driving the probe into the ground.

The relatively low cost of taking groundwater samples with DPS allows the collection of a larger number of samples both horizontally and vertically than could be done using conventional rigs. This density of sample taking provides a better idea of where source zones are and contaminant plume architecture which maximizes permanent monitoring well placement efficiency and the design of the remedy.

Direct-Push Technologies
- Direct-Push Platforms
- Geotechnical Sensors
- Groundwater Samplers
- Membrane Interface Probes
- Soil and Soil-Gas Samplers

Explosives
Fiber Optic Chemical Sensors
Gas Chromatography
Geophysics
- Ground Penetrating Radar
- Magnetics for Environmental Applications

High-Resolution Site Characterization (HRSC)
Immunoassay
Infrared Spectroscopy
Laser-Induced Fluorescence
Mass Flux
Mass Spectrometry
Open Path Technologies
- UV-DOAS
- OP-FTIR
- LIDAR
- Raman Spectroscopy
- Tunable Diode Lasers (TDLs)

Passive (no purge) Samplers
Test Kits
X-Ray Fluorescence

Field Analytic Technologies Home
Ask an Expert
Problem Solver

Twenty-five ton CPT Rig. Courtesy of Precision Sampling.

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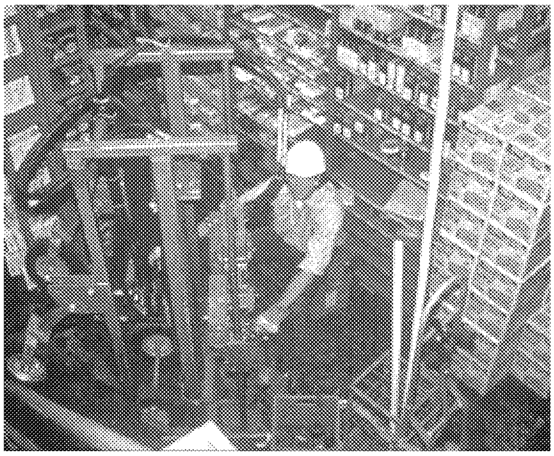
Typical Uses



Hand truck percussion hammer rig.
Courtesy of Precision Sampling.

Direct-push systems provide advantages when collecting groundwater samples. In particular, direct-push systems are quicker and more mobile than traditional drill rigs. Sampling and some data collection are faster, reducing the time needed to complete an investigation and increasing the number of points that can be sampled during the investigation. Shorter screen lengths allow sampling of precise depth intervals, which is especially important when sampling a contaminant plume from a source with a complex architecture such as may be found with dense nonaqueous phase liquids (DNAPL).

In spite of these advantages, there are some limitations of groundwater sampling using direct-push systems. Because direct-push sampling tools are not developed like conventional monitoring wells, samples may be turbid. Turbidity is a particular concern when the target analytes are metals or organic compounds with a tendency to be sorbed onto the surfaces of clays silts, or naturally occurring organic compounds such as humic acids. When sampling for these analytes, investigators should consider using small wells installed using direct-push tools. These wells can be developed like conventional monitoring wells and provide comparable quality samples. There are samplers, such as the BAT system (see below), that use ceramic or other porous tips to draw water through that will provide a low-turbidity sample.

Direct push groundwater sampling tools/techniques generally can be divided into three groups: sealed-screen samplers, exposed-screen samplers, and open-hole sampling.

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Sealed-Screen Samplers

Sealed-screen samplers typically consist of a short screen contained within a sealed, water-tight body. To collect the sample, the tool is driven to the desired depth where the protective outer rod is withdrawn exposing the screen to groundwater. The water flows through the screen and into the drive rods or sample chamber. O-ring seals placed between the drive tip and the tool body help ensure that the sampler is water tight as it is driven to the target depth. The integrity of the seal can be checked by lowering an electronic water level indicator into the sampler prior to withdrawing the outer rod. Because the tool is sealed, the potential for cross contamination is greatly reduced and a true depth-specific sample can be collected. The sample volume collected with some sealed screen samplers is limited by the volume of the sample chamber.

These types of samplers can only sample one interval per push. If the sampler uses the walls of the rod for containing the groundwater until it can be retrieved by bailer or pump, care should be taken to ensure that the target contaminants are not sensitive to interaction with iron (e.g., dissolved oxygen, redox potential, and trace metals).

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Exposed-Screen Samplers

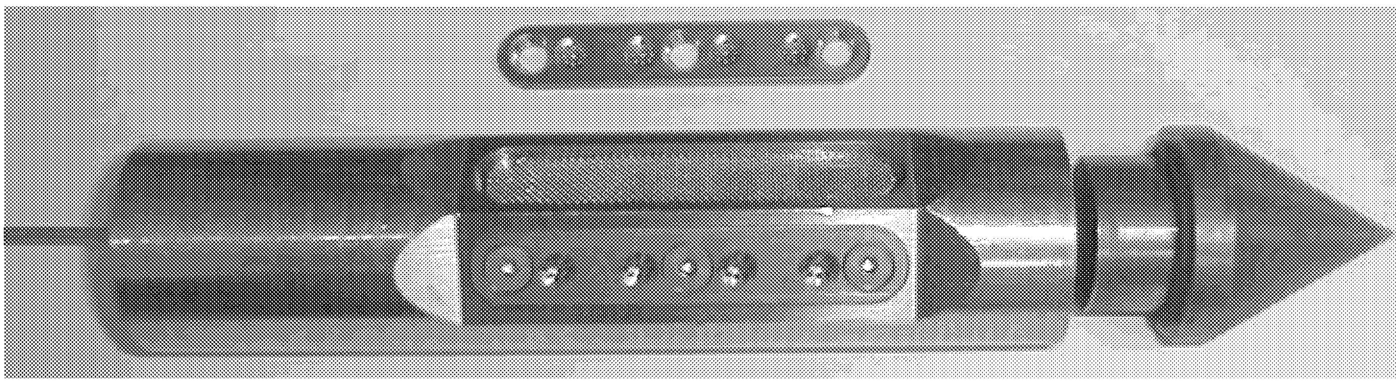
Waterloo Profiler® Courtesy Precision Sampling, Inc.

Exposed-screen samplers are capable of collecting groundwater samples at multiple intervals as the sampling tool is advanced, without having to withdraw the tool for sample collection or decontamination. The terminal end of a typical exposed-screen sampler has a 6-inch- to 3-foot-long screen made up of fine-mesh, narrow slots, or small holes. The screen remains open to formation materials and water while the tool is advanced. This allows samples to be collected either continuously or periodically as the tool is advanced to vertically profile groundwater chemistry and aqueous-phase contaminant distribution.

Exposed-screen samplers can be used to measure water levels at discrete intervals within moderate- to high-yield formations to assist in defining vertical head distribution and gradient. Additionally, some of these tools can be used to conduct hydraulic tests at specific intervals to characterize the hydraulic conductivity of formations to identify possible preferential flow pathways and barriers to flow.

The Waterloo Profiler® minimizes the potential for cross contamination. It uses a 6-inch-long, uniform diameter, stainless-steel sampling tool into which several inlets or sampling ports have been drilled and covered with fine-mesh screen. As the tool is advanced, distilled or deionized organic-free water is slowly pumped down tubing that runs inside the drive rod and leads to the sampling ports in the tool. The water keeps groundwater from entering the tool while it is advanced. A peristaltic pump is typically used for water head depths less than 25 feet. A double-valve pump can be used for sampling at greater depths.

After the first target interval is reached, the flow of the pump is reversed and the sampling tube is purged so water representative of the aquifer is obtained. After the sample is collected, the pump is reversed and distilled or deionized organic-free water is again pumped through the sampling ports. The tool is then advanced to the next target interval where the process is repeated.



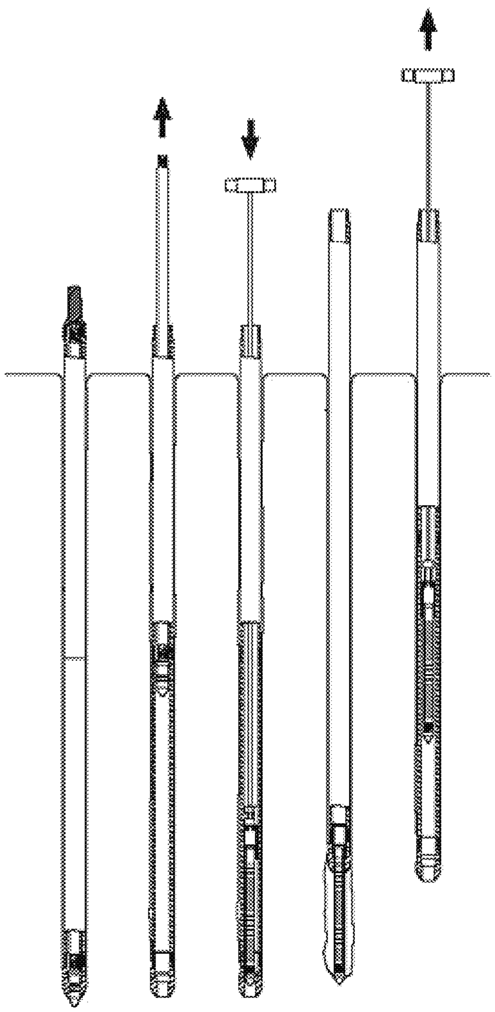
Waterloo Advanced Profiling System™ Courtesy Stone Environmental, Inc.

The Waterloo Advanced Profiling System (WaterlooAPS™) allows physiochemical data acquisition. The stainless-steel profiling tip has 16 ports arranged in four rows, resulting in an open sampling interval approximately 2.5 inches in length. Each of the rows is recessed and fitted with dual filter screens. The mesh size of the inner screen can be changed to reduce turbidity or optimize sampling productivity. To minimize sorption of contaminants to system materials, stainless steel tubing convey groundwater from the profiling tip to the sample collection apparatus at the surface. A sacrificial profiling tip allows retraction grouting of completed profiling boreholes. Groundwater samples are collected at discrete depth intervals using either a peristaltic or downhole nitrogen gas-drive pump, depending on depth to the water table. Samples are collected directly into glass, zero-headspace, in-line sample containers that prevent sample contact with system materials and ambient air. The containers are located on the suction side of the peristaltic pump to prevent contact with pump head tubing during use of that sampling method.

The BAT® system consists of a tip, screen, and housing with sampling chamber. The top of the chamber is sealed with a disc containing a flexible septum. The tip is constructed of high-strength thermoplastic or stainless steel. The screen, which is either ceramic or porous polyethylene, allows water to enter the sampling chamber when put under vacuum. To take a sample, the tool is driven to the desired sampling depth. A sample holder containing an evacuated sample vial (35 to 500 mL) with a septum cap and a double-ended hypodermic needle is then lowered down the push rod. When the vial encounters the top of the sample chamber, the needle penetrates the chamber septum at the same time it penetrates the vial septum, allowing water to enter the vial. When the vial is full, it is retrieved and stored for subsequent analysis. The procedure is repeated until sufficient water is collected to meet analytical needs. The tool can then be driven to another depth and sampled or withdrawn, cleaned, and driven in a different location.

Open-hole sampling is conducted by advancing drive rods with a drive point to the desired sampling depth. Upon reaching the sampling depth, the rods are withdrawn slightly which separates them from the drive tip and allows water to enter. The water can be sampled by lowering a bailer into the rods or by pumping. The open-hole method is only feasible within formations that are fairly cohesive, otherwise the formation soil may flow upwards into the rods when they are withdrawn, preventing water samples from being collected. With single-rod systems, open-hole sampling can only be conducted at one depth within a borehole because the borehole cannot be flushed out between sampling intervals and cross-contamination may occur.

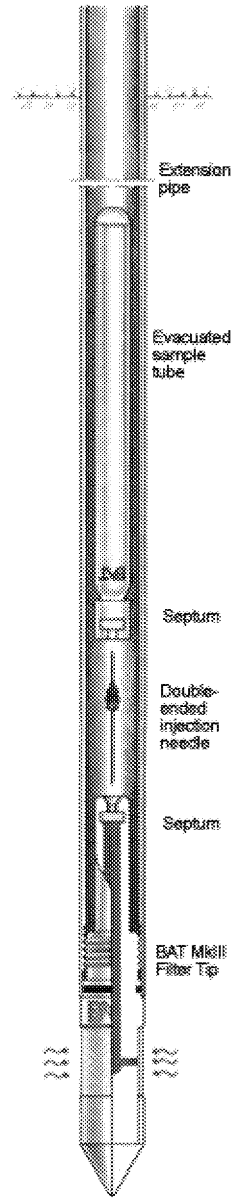
Dual-tube systems provide continuous soil sampling capabilities. The cores can be examined and chemically screened as they are taken, and decisions made as to whether a groundwater sample should be taken at that level. Because the dual tube has an outside casing that is driven with the drive point, it minimizes drag down potential and allows multiple-level sampling within the outer casing. The water that is in the casing between sampling points will need to be purged to ensure a representative sample. Many vendors that offer sealed sampling tools prefer to use dual-tube systems to advance the rods to the desired point of sampling and either lower the screen to the bottom of the hole and withdraw the outer casing allowing fresh water in, or drive the sampler to a point slightly ahead of the rods. By lowering the tool to the bottom of the already driven hole or driving it a short distance into the ground ahead of the rods, the life of the tool is extended and excellent stratigraphical information is obtained from the cores.



(1) Advance outer casing to bottom of screen interval.
(2) Remove inner rod string leaving open outer casing.
(3) Lower screen to bottom of casing and hold in place with extension rods.
(4) Retract casing to expose screen to formation, remove extension rods.
(5) Retrieve screen after development, sampling, and slug testing.

Repeat the above sequence for the entire length of the probe push.

Dual-Tube Groundwater Profiler. Courtesy of Geoprobe Systems®



BAT® Sampler. Courtesy BAT Geosystems, AB

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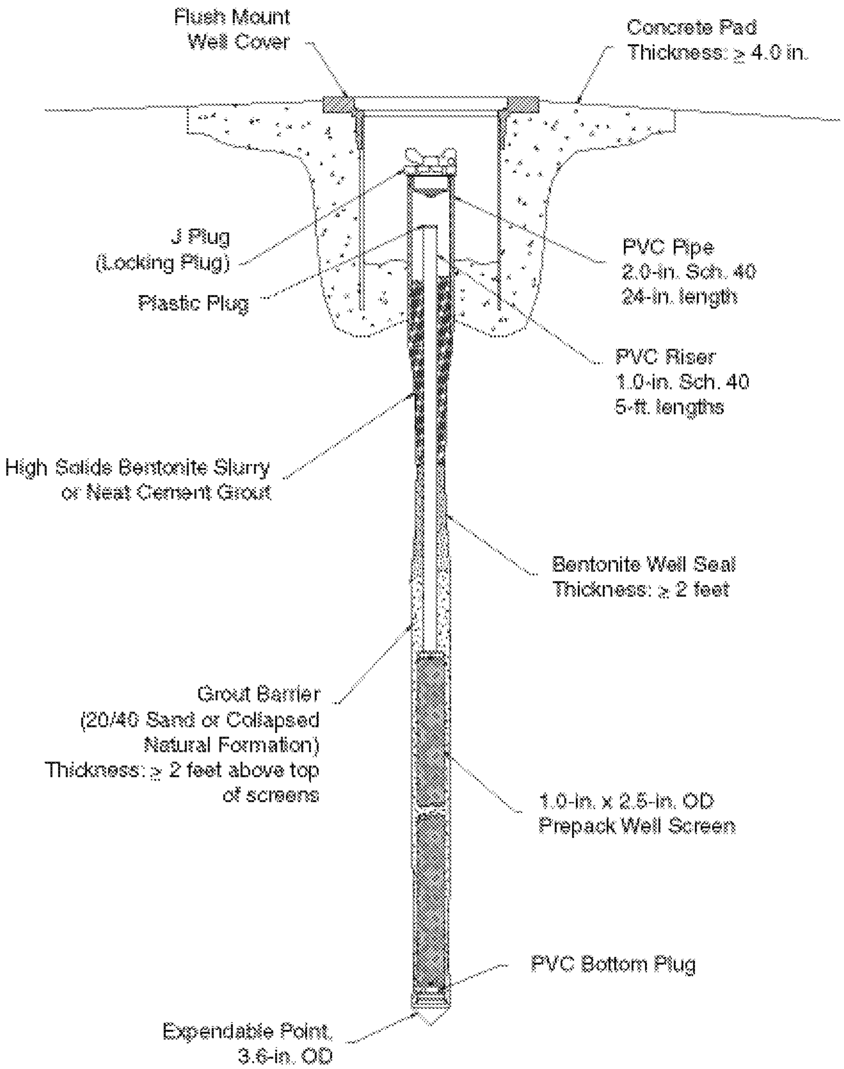
Monitoring Wells and Piezometers

Direct-push systems can also be used to install temporary or permanent monitoring wells and piezometer. These wells can be installed in several ways. The first and most direct is to drive a well point to the depth to be sampled. Well points are generally constructed of slotted steel pipe or continuous-wrap, wire-wound, steel screens with a tapered tip. If the well point will be left in the ground for any length of time, a seal to prevent infiltration of surface water will be needed.

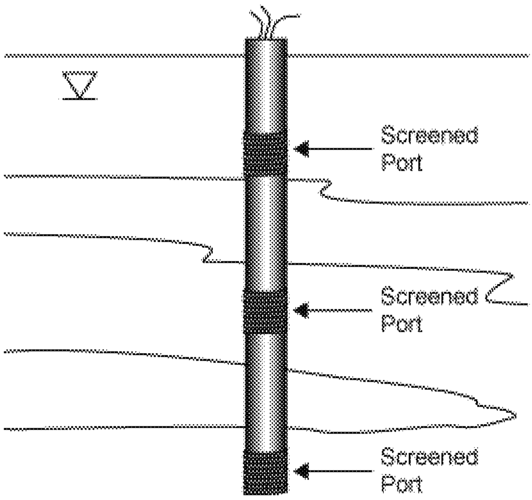
A second method of well installation is to drive a rod casing with an expendable tip to the depth to be monitored. The well string is placed in the casing with the screen resting on the expendable tip. Depending upon the inside diameter of the drive casing and the outside diameter of the well casing, it may not be possible to set a sand filter around the screen. If a sand pack is not possible, the outer casing is withdrawn and the formation is allowed to collapse around the screen and well casing. This technique will probably not yield low turbidity samples in formations that are rich in fines. If a dual-tube rig is used, a continuous soil core can be taken that will aid in selecting monitoring depths.

The third technique is similar except that it uses well screens with prepacked filters. Direct push wells completed in this fashion are comparable to conventional wells. A modular sleeve with fine sand or bentonite can be placed above the filter to prevent infiltration of grout or other material used for sealing the annular space.

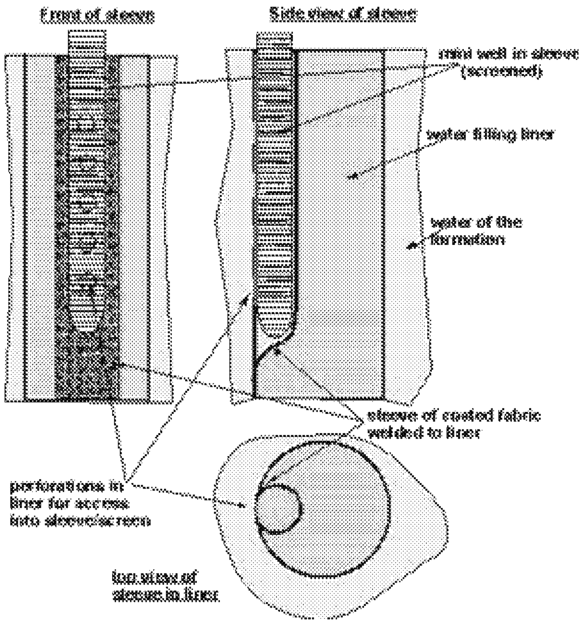


Direct-push monitoring well. Courtesy of Geoprobe Systems®

Multiport collectors are another technological advance that expands the single-use functionality and increases the understanding of aquifer characteristics. In one system, a multiport sleeve and a deflated membrane are placed using a hollow rod. Holding the assemblage in place, the rod is retracted, and the membrane is inflated, usually with water. This pushes the multilevel sampler to the side of the borehole. Small diameter screens with blank casing are pushed down into the sleeve. Perforations in the sleeve allow groundwater to enter the screens. Generally up to three depths can be sampled from a single borehole. The whole assemblage can be removed by taking the miniwells out of the sleeves and deflating the membrane, or it can be left downhole to function as a multiport monitoring well.



Multilevel sampler.



Multiport sampler. Courtesy of Flexible Liner Underground Technologies.

Another type of multiport sampler uses blank PVC casing as a support and places stainless steel screened ports that are connected to the surface with tubing at depths of interest. The 2-inch casing with ports is lowered into the outer drive rod casing to the bottom of the hole. As the casing is pulled, the soil is allowed to naturally collapse around the string. Depending upon the configuration, the system can measure up to 15 different zones.

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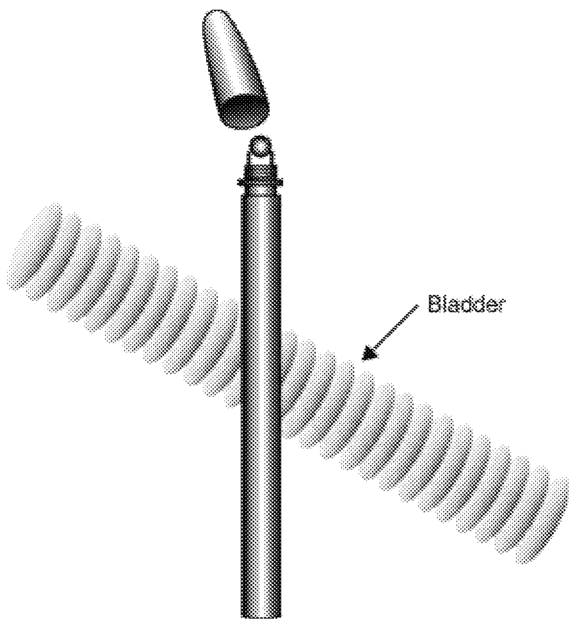
Sample Collection Devices

In the simplest sampling tools (e.g., open hole), groundwater can be collected as it would be from a conventionally-installed well. Miniaturized water level indicators and small-diameter bailers are available for most direct push wells.



Mechanical bladder pump. Courtesy of Geoprobe Systems®

Another commonly-used sample collector is an inertial pump. Inertial lift pumps consist of a discharge line (either flexible tubing or rigid pipe) with a ball-check foot valve attached to its lower end. In operation, the tube is lowered into a water column and moved through an up and down motion, to achieve discharge of water. As the pump is moved upward, water that has entered the pump under hydrostatic pressure is lifted upward, held in the pump by the seated foot valve. When the upward motion of the pump is stopped, the inertia of the water column inside the pump carries it up and out of the discharge line. As the pump is pushed downward, the foot valve opens, allowing the pump to refill. If inertial-lift pumps are cycled rapidly prior to or during sample collection, some loss of VOCs and/or dissolved gases could occur in the discharge stream as well as increasing sample turbidity (EPA 2004).

Within the constraints of well depth and diameter, a wide variety of pumps can be used to collect groundwater samples. Pumps are available with diameters as small as 3/8 inch for use with direct-push installed wells. Examples of pump types include bladder, mechanical bladder, and double valve. Some of these pumps have additional features for use with mini-wells, such as rounded ends so that they can be positioned more easily in small diameter wells without hanging up.

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Advantages

Field analysis and direct-push systems are often used to speed collection and reduce costs on projects where the sites are large, a high volume of data points are needed, the sites are partly or totally inaccessible by a large drill rig, or to minimize sampling disturbances in sensitive habitats.(See http://www.triadcentral.org for examples).

Groundwater sampling using direct-push technologies provides many advantages over sampling using conventionally-installed wells. Direct-push systems are quicker and more mobile than traditional drill rigs. Small percussion hammer rigs can even be used to sample inside buildings. The smaller footprint of many of the direct-push rigs also minimizes surface and subsurface disturbance. Sampling and data collection are faster, reducing the time needed to complete an investigation and increasing the number of sample points that can be collected during the investigation.

Direct-push technologies are particularly well suited for application of the Triad Approach to site investigations for sites with shallow subsurface contamination in unconsolidated soils and sediments. The Triad Approach makes use of on-site analytical tools, in conjunction with systematic planning and dynamic work plans, to streamline sampling, analysis, and data management conducted during site assessment, characterization, and cleanup.

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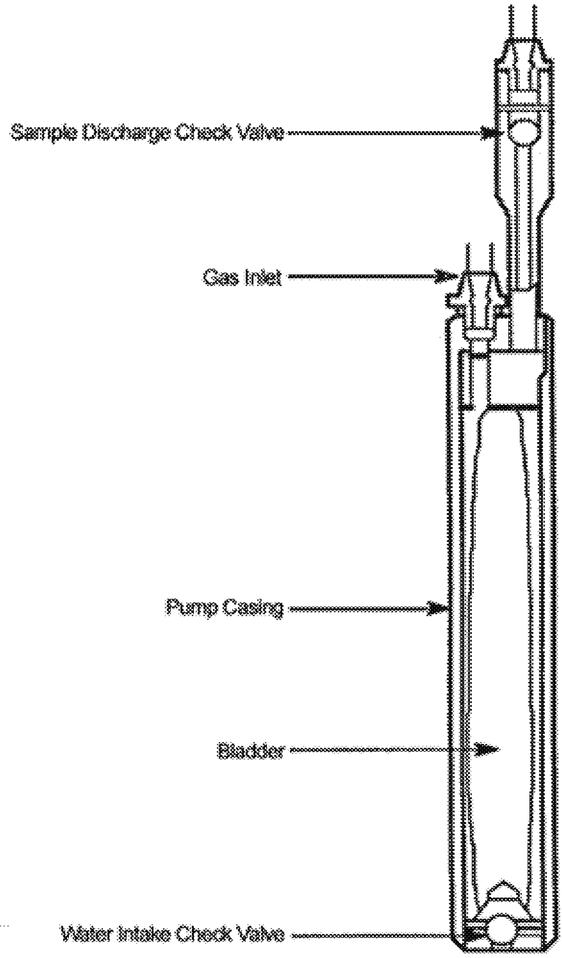

Bladder Pump. After EPA 1993.

Limitations

Groundwater sampling using direct-push systems has limitations that are important to keep in mind when considering its use for site characterization. Direct-push technologies cannot be used to collect samples from consolidated aquifers, and, in general, are limited to depths of less than 100 feet. Because some of the tools lack filters or have filters that are less effective than those of completed monitoring wells, samples may be turbid. Turbidity can usually be reduced by using wells with prepacked filters, selecting sampling tools with more complete filtration systems, or using low-flow sampling techniques. The smaller sampling interval, an advantage in some cases, can be a limitation when the goal of the investigation is depth-averaged trend analysis. Also, the smaller-diameter sampling chambers available for some sampling tools can sometimes lead to smaller available sample volumes.

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Cost Data

Studies indicate that direct-push analytical systems may provide significant savings over conventional site assessment and characterization methods. Cost information varies greatly among the different technologies, as well as for projects of different scope and geologic conditions. The sites listed below provide information about the costs associated with a variety of technologies.

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Resources

EPA. 2005. Groundwater Sampling and Monitoring with Direct Push Technologies, EPA 540/R-04/005. Office of Solid Waste and Emergency Response, 78 pp. http://www.clu-in.org/download/char/540r04005.pdf

EPA. 1993. Subsurface Characterization and Monitoring Techniques: A Desk Reference Guide, Volume I: Solids and Ground Water Appendices A and B, EPA 625/R-93/003a. Office of Research and Development, 498 pp. http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30004L8E.txt

Puls, R. and M. Barcelona. 1996. Ground Water Issue: Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures, EPA/540/S-95/504. U.S. Environmental Protection Agency, 12 pp. http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000G23N.txt

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Multi-Level Samplers

Multi-level samplers, most of which are exposed-screen samplers, are DPT equipment capable of collecting groundwater samples at multiple intervals as the sampling tool is advanced, without having to withdraw the tool for sample collection or decontamination. The terminal end of a typical multi-level sampling tool has a 6-inch- to 3-foot-long screen made up of fine-mesh, narrow slots, or small holes. The screen remains open to formation materials and water while the tool is advanced (Figure 2.2). This allows samples to be collected either continuously or periodically as the tool is advanced to vertically profile groundwater chemistry and aqueous-phase contaminant distribution.

Multi-level samplers can be used to measure water levels at discrete intervals within moderate- to high-yield formations to assist in defining vertical head distribution and gradient. Additionally, some of these tools can be used to conduct hydraulic tests at specific intervals to characterize the hydraulic conductivity in formation materials to identify possible preferential flow pathways and barriers to flow (Butler et al., 2000; and McCall et al., 2000).

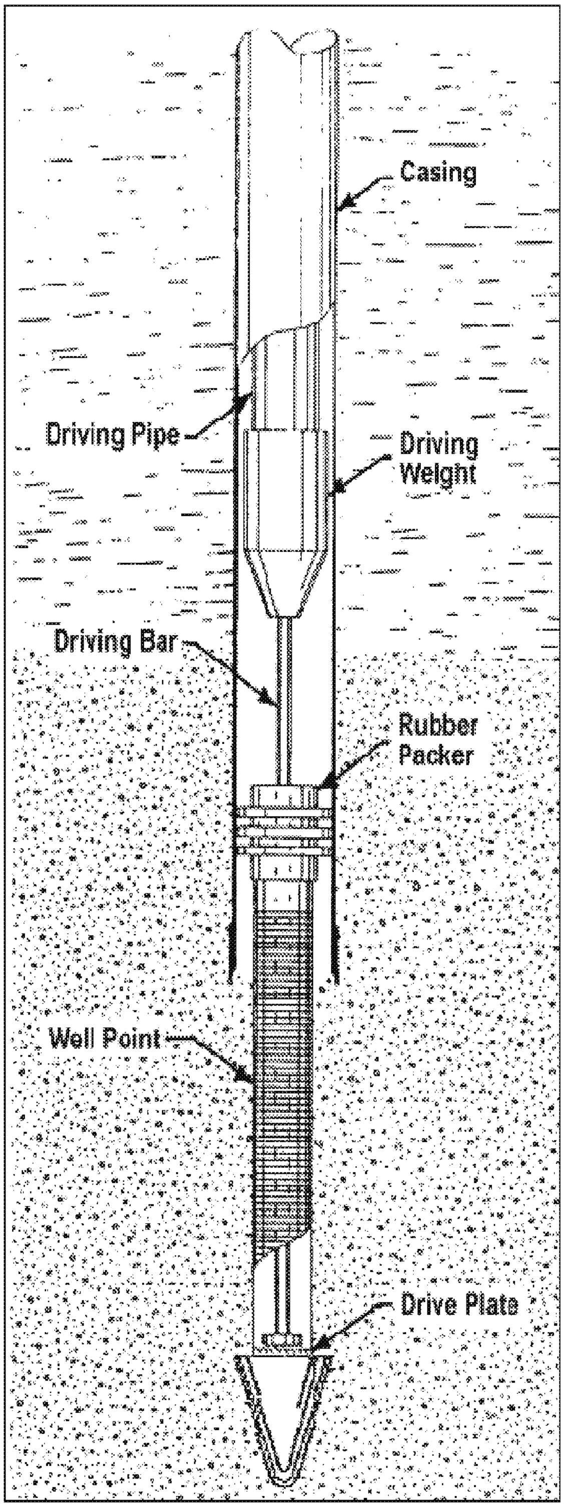
A drawback to multi-level sampling is the possible drag-down by the screen of contamination from zones above the desired sampling interval (Figure 2.3) (Pitkin et al., 1999). The Waterloo Profiler minimizes the potential for cross- contamination. It uses a 6-inch long, uniform diameter, stainless-steel sampling tool into which several inlets or sampling ports have been drilled and covered with fine-mesh screen. As the tool is advanced, distilled or deionized organic-free water is slowly pumped down tubing that runs inside the drive rod and leads to the sampling ports in the tool (Figure 2.4). The water keeps groundwater from entering the tool while it is advanced. A peristaltic pump is typically used for depths less than 25 feet; a double-valve pump can be used for sampling at greater depths.

After the first target interval is reached, the flow of the pump is reversed and the sampling tube is purged so water representative of the aquifer is obtained. After the sample is collected, the pump is reversed and distilled or deionized water is again pumped through the sampling ports. The tool is then advanced to the next target interval where the process is repeated (Figure 2.5).

Several field studies (Cherry, et al., 1992; Pitkin, et al., 1994; Pitkin, et al., 1999) have demonstrated that the Waterloo Profiler is capable of providing a very detailed view of contaminant plumes—particularly in complex stratified geological materials—without the effects of drag-down and the cross contamination of samples. However, because a peristaltic pump is typically used to collect samples when the sampling depth is less than 25 ft below ground surface (bgs), there may be a negative bias in samples collected for analysis of VOCs or dissolved gases. To avoid this potential bias, VOC samples should be collected in-line, ahead of the pump, and a sufficient volume of water should be pumped through the system to account for the initial filling of the containers when a negative head space was present.

Another multi-level sampler, the VERTEK ConeSipper®, attaches directly behind a standard cone penetrometer to collect groundwater as the cone penetrometer testing (CPT) is advanced. An inert gas flows to the ConeSipper® to control the rate of sample collection and to purge and decontaminate the device down hole. The ConeSipper® is equipped with two filters, which help minimize turbidity in the samples. The primary filter is a stainless steel screen whose openings can range in size from 51 to 254 µm. A secondary filter, which can be made from sintered stainless steel and comes with opening sizes ranging from 40 to 100 µm or regular

Figure 2.2
Exposed-Screen Sampler–Well Point Driven below the Base of a Borehole



Source: ASTM (2001e)

Figure 2.3
Schematic Illustration of Degrees of Drag Down Potentially Induced by Direct Push Sampling Devices

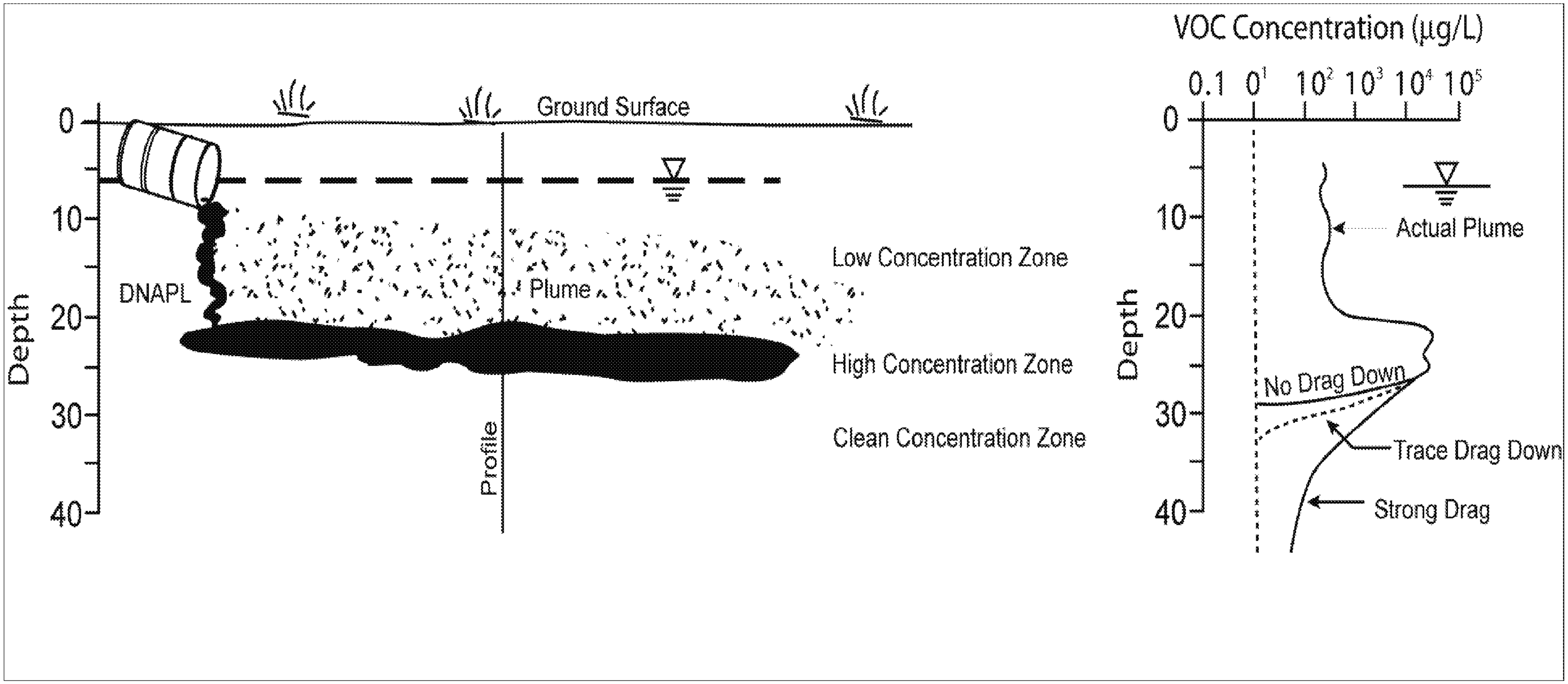
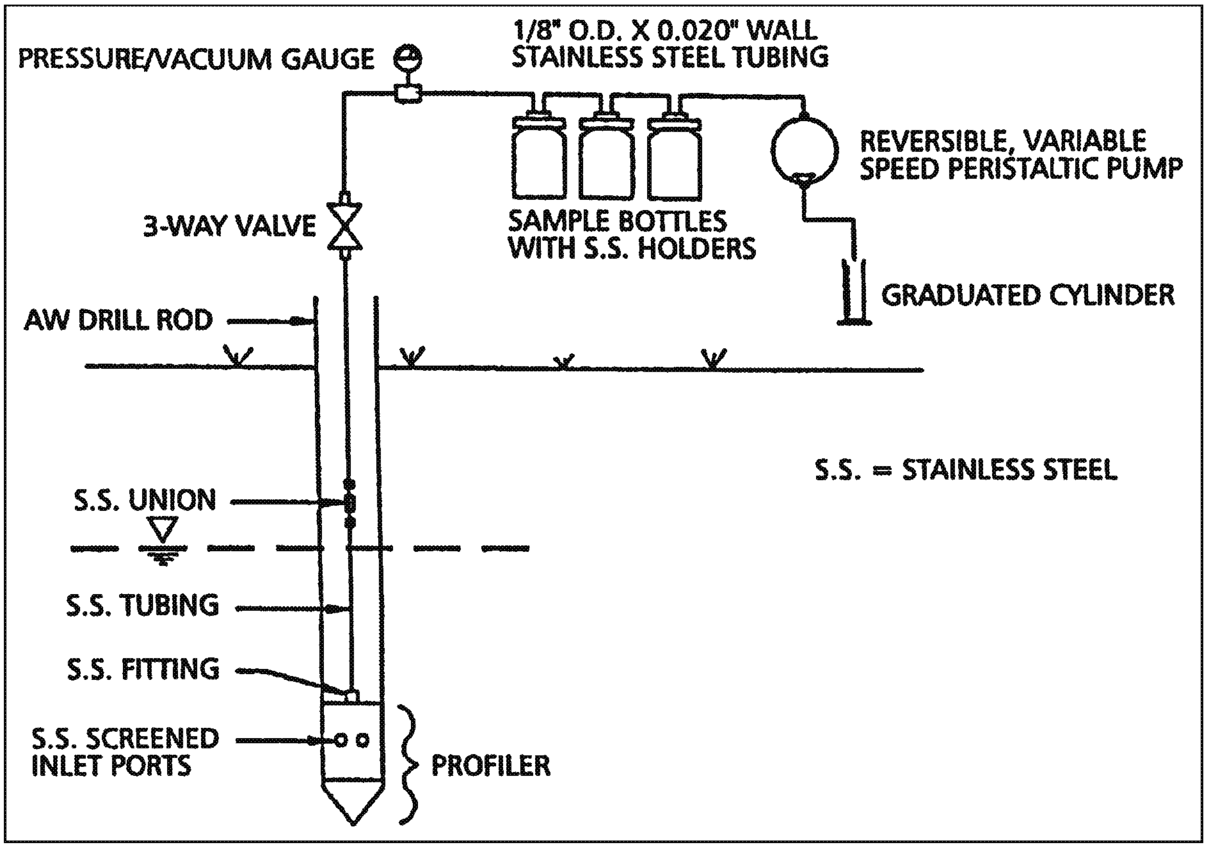


Figure 2.4
Operation of the Waterloo Profiler



Source: Pitkin et al. (1999)

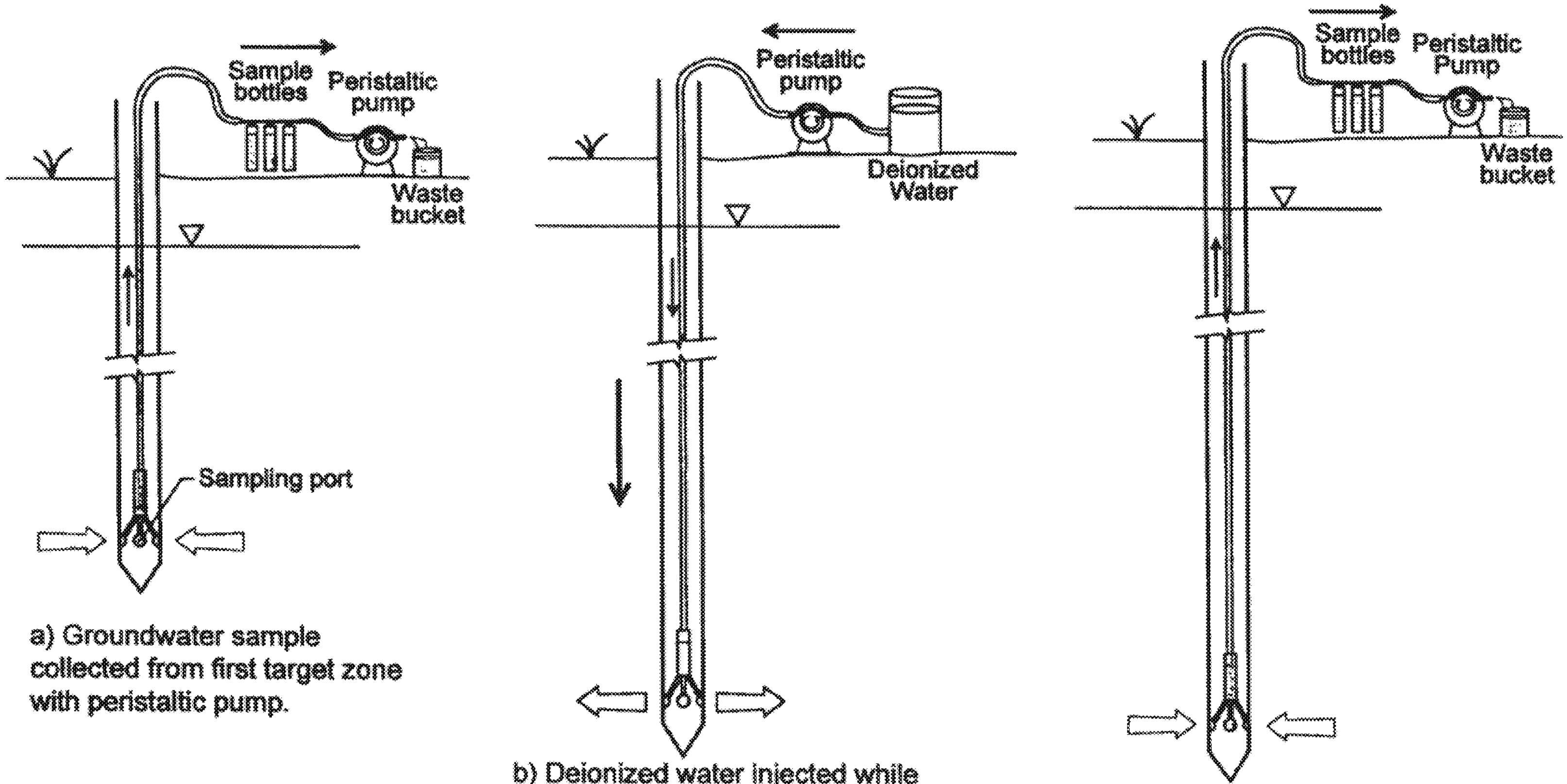
stainless steel with openings ranging in size from 38 to 74 µm, removes fines (Applied Research Associates, 2004).

Open-Hole Sampling Methods

Open-hole sampling is conducted by advancing drive rods with a drive point to the desired sampling depth. Upon reaching the sampling depth, the rods are withdrawn slightly which separates them from the drive tip and allow water to enter the rods. The water can be sampled by lowering a bailer into the rods or by pumping. The open-hole method is only feasible within formations that are fairly cohesive, otherwise the formation may flow upwards into the rods when they are withdrawn, preventing samples from being collected.

With single-rod systems, open-hole sampling can only be conducted at one depth within a borehole because the borehole cannot be flushed out between sampling intervals and cross-contamination may occur. Dual-tube systems, on the other hand, can be used to conduct multi-level sampling.

Figure 2.5
Collecting Samples From Discrete Depths (Profiling) Using the Waterloo Drive-Point Profiler



a) Groundwater sample collected from first target zone with peristaltic pump.

b) Deionized water injected while advancing tool to prevent sampling ports from becoming plugged.

c) Groundwater sample collected from second target zone with peristaltic pump.

Source: Precision Sampling, Inc.

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A New System for Ground Water Monitoring

by Bengt-Arne Torstensson

Abstract

This paper describes a new system for ground water monitoring, "the BAT System," which includes the following functions: (a) sampling of ground water in most types of soils, (b) measurement of pore water pressure, and (c) in situ measurement of hydraulic conductivity. The system can also be used for tracer tests. The system utilizes a permanently installed filter tip attached to a steel or PVC pipe. Installation is normally performed by pushing the tip down to the desired depth. The filter tip can also be buried beneath a landfill. The primary feature of the new system is that the filter tip contains a self-sealing quick coupling unit, which makes it possible to temporarily connect the filter tip to adapters for various functions, e.g. water sampling and for measurement of pore pressure and hydraulic conductivity. The new technique makes sampling of both pressurized water and gas possible. Samples are obtained directly in hermetically sealed, pre-sterilized sample cylinders. Sampling of ground water and measurement of pore pressure can be repeated over a long period of time with undiminished accuracy. This technique is also well-adapted for taking water samples from different strata in a soil profile, in both the saturated and unsaturated zones. Actual installations range from 0.5 to 60m depth.

System Description

General

The new system for ground water monitoring includes the following functions:

- Sampling of ground water (gas and fluid phases)
- Measurement of pore water pressure
- In situ testing of hydraulic conductivity
- Tracer test for monitoring ground water flow.

The system utilizes a filter tip that is permanently installed in the ground. The filter tip is attached to a 1-inch extension pipe made of steel or of plastic.

The different functions listed above operate by way of different test adapters that are lowered down the pipe. The adapters make a tight seal with the filter tip through the aid of a special quick-coupling unit, which comprises a pre-stressed disc of resilient material and a hypodermic needle.

The basic principle of the new system is that one set of test adapters can serve hundreds of permanently installed filter tips.

BAT filter tip

The key element in the new system for ground water monitoring is the BAT filter tip, shown in Figure 1. This tip consists basically of a thermoplastic body and a filter made of porous plastic (polypropylene) or sintered ceramic. The tip is sealed with a pre-stressed disc of resilient material, e.g. synthetic rubber or crude rubber. The rubber disc is mounted in a nozzle and functions as both a seal and an automatic one-way valve. The filter tip is threaded onto a 1-inch

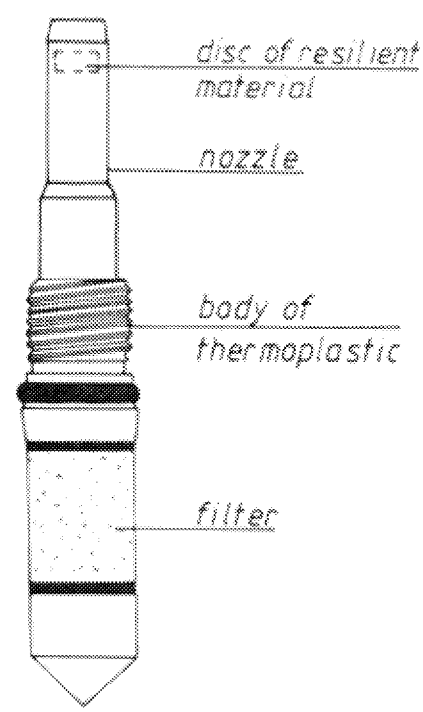

Figure 1. Filter tip

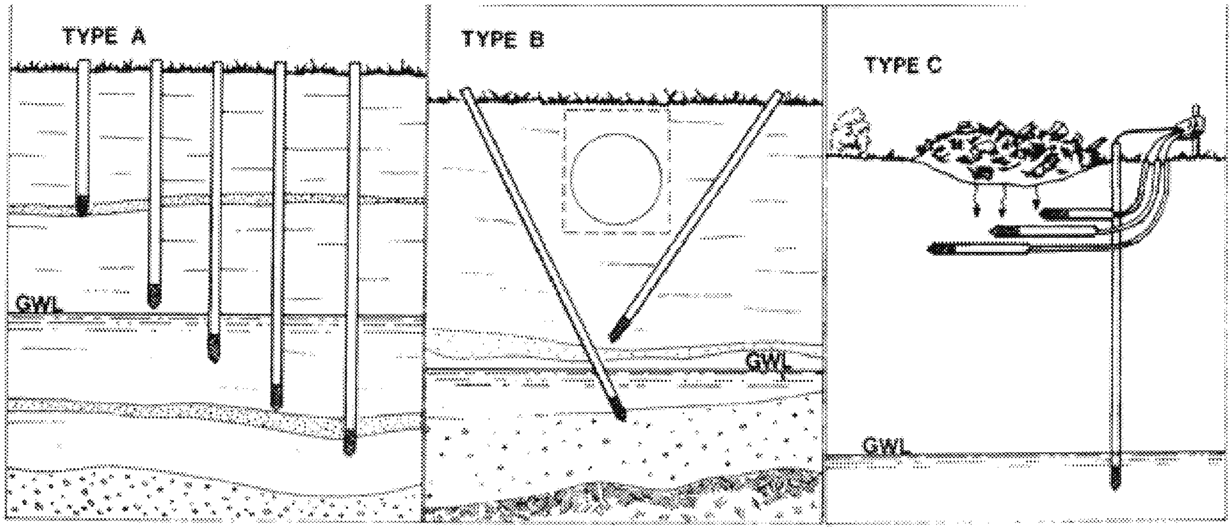

Figure 2. Different modes of installation of the filter tips: a) cluster; b) inclined installation to reach beneath existing underground structures, and c) "horizontal" installation beneath a landfill or a similar structure

extension pipe and is normally installed into the soil simply by pushing it down to the desired level. Figure 2 illustrates different modes of installation of the filter tips. Figure 2a shows a cluster of filter tips installed at different depths for sampling of ground water and measurement of pore pressure in various soil strata. Figure 2b shows an inclined installation in order to reach beneath an underground storage tank etc., whereas Figure 2c shows filter tips that are buried beneath a landfill.

The standard filter tip (Figure 1) is furnished with a reinforcing core of Teflon-coated stainless steel. When installed in fine-grained soils, this filter tip can sustain an installation force of approximately 2 tons. For harder soils special filter tips have been developed, namely one that has a body of stainless steel and another type (heavy duty filter tip), which has a filter molded inside the body of stainless steel or brass. It is also possible to install the filter tips in pre-drilled holes and to seal off the test section with a bentonite slurry.

The different test adapters make a tight, temporary connection to the filter tip with the aid of a hypodermic needle (Figure 3). When the test adapter is lowered down the extension pipe, it is coupled to the nozzle in the filter tip and gravity draws the hypodermic needle downward, penetrating the rubber disc, mounted in the filter tip. The needle provides a hydraulic connection between the interior of the filter tip and the test adapter.

Eight years experience has shown that the rubber disc can be penetrated by the hypodermic needle hundreds of times without loss of its automatic, self-sealing, one-way valve function.

Pore pressure measurement equipment

Figure 4 shows a photo of the test adapter for pore pressure measurements. The test adapter is lowered onto the filter tip for each pore-pressure reading.

The pore pressure adapter contains a hypodermic needle and an electronic pressure transducer, which is connected to a battery-operated digital readout unit via a cable. Between the hypodermic needle and the diaphragm of the pressure transducer is a fluid-filled cavity. The readout unit's display clearly indicates when the needle penetrates the rubber disc in the filter tip. A stable value for the pore pressure is nor-

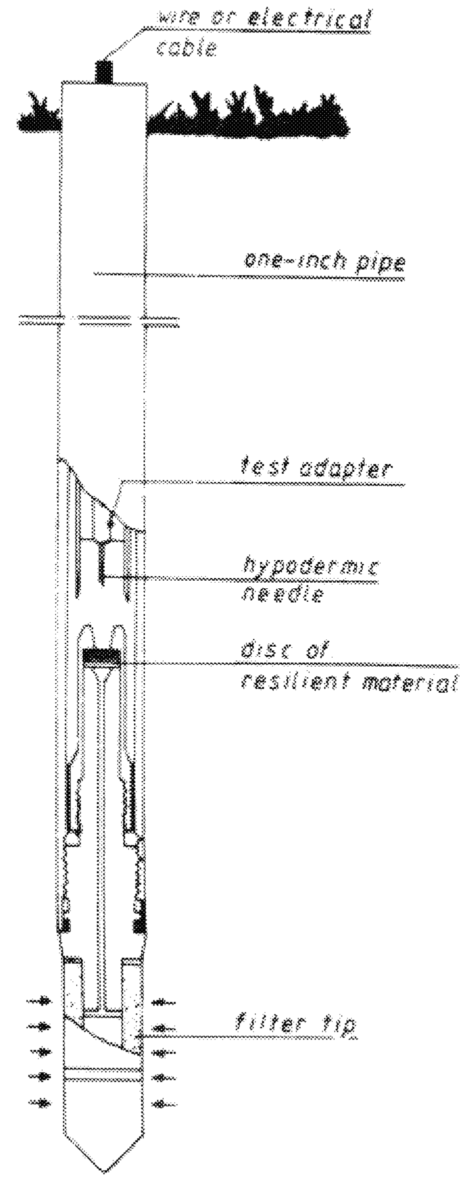

Figure 3. A test adapter is lowered onto the filter tip. The adapter makes a tight, temporary connection to the filter tip with the aid of a hypodermic needle

mally obtained after a few minutes, even in highly plastic clays. The standard pressure range of the pore pressure adapter is from -10 to 150m of water column.

Ground water sampling equipment

Figure 5 shows a schematic diagram of the equipment used for sampling ground water and gas. Samples are obtained in hermetically sealed, pre-sterilized and evacuated glass cylinders. A sample cylinder, sealed with a rubber disc, is mounted in a sampling adapter. The adapter is equipped with a double-sided hypodermic needle, mounted on a track in the adapter nose.

Prior to evacuation, the sample cylinder can be filled with nitrogen in order to increase the chemical inertness of the system. The interior of the cylinder can be coated with Teflon if required.

The glass containers can be used to a maximum pressure of 200m of water column. For high-pressure applications, containers of stainless steel must be used.

The standard sampling equipment is designed for 1-inch extension pipes. This version can hold sample containers with a volume of 35ml (Figure 6). By using extension pipes with a greater diameter than 1 inch, e.g. 1.5- or 2-inch diameter, the sample volume can be increased to 200-500ml.

Samples of ground water and/or gas are taken by lowering the adapter down the extension pipe. When the adapter connects to the nozzle of the filter tip the double-sided hypodermic needle will penetrate both the rubber disc in the nozzle and the rubber disc in the sample cylinder. This provides a connection between the sample cylinder and the interior of the filter tip. Due to the underpressure in the sample cylinder, ground water (e.g. pore water) will be sucked into the container via the filter tip.

The penetration of the double-sided hypodermic needle through the rubber discs is aided by use of a chain of weights attached to the sampling adapter.

Some special features of the new ground water and gas sampler include:

- samples of ground water and gas can be obtained with a high degree of cleanliness: no air contact and no external contamination
- samples can be obtained with constant quality—independent of the skillfulness of the person taking the sample
- volatile constituents (e.g. organic solvents) can be accurately sampled
- samples of ground water can be collected from almost all types of soils, including impervious clay
- sampling can be carried out with undiminished accuracy at great depths
- samples can be easily collected, even when freezing temperatures occur on the ground surface
- the sampling technique minimizes risks that the operator comes into contact with dangerous chemicals, etc.

It should also be noted that the new technique enables sampling of pressurized water. If the sample adapter remains connected to the filter tip the pressure in the sample container will finally equalize the pore water pressure in the soil. The time needed for pressure equalization is a function of the hydraulic conductivity of the soil. When it is disconnected from the filter tip the sample adapter closes automatically, i.e. the pressure in the sample cylinder is preserved as the water and/or gas sample is taken to the laboratory.

Figure 4. Test adapter for pore pressure measurement being inserted into the one-inch extension pipe

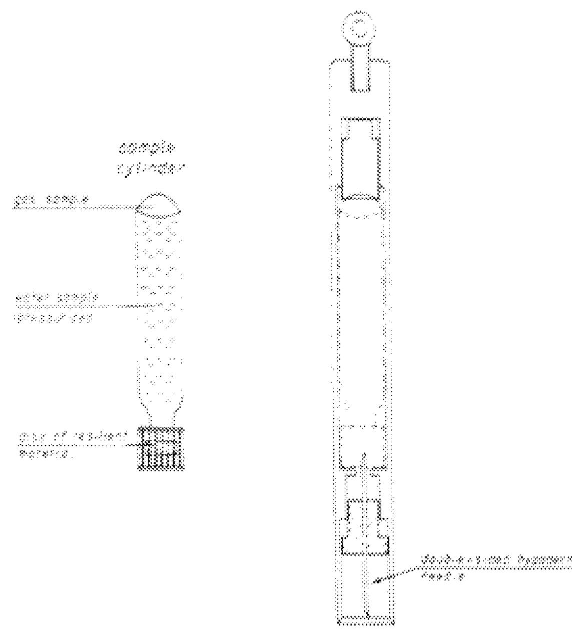

Figure 5. Schematic of test adapter for sampling of ground water and gas

The ability to sample pressurized water is greatly important in the analysis of dissolved gases in water.

Results from pore water sampling

In 1981, a test series using the new ground water monitoring system was initiated at the Verka basin, 35km north of Stockholm.

At the Verka site, the installation of the BAT System represents only a small part of a larger project with basic aims of: (a) making a detailed study of the circulation of salts in the soil layers, and (b) monitoring both the movement and the recharge of ground water (Nilsson and Armolik 1980).

The soil profile at the Verka test location consists of a very soft clay to a depth of about 16m. The clay is very homogeneous to a depth of about 12m. In the depth interval of 12-16m the clay is slightly varved.

Filter tips were installed at three test locations. At one site four filter tips were installed at the depths of 9, 12, 14 and 16m (Figures 7 and 8). All filter tips were installed in a very soft, impervious clay. The filter tip at 16m depth was, however, situated close to a more pervious bottom soil layer. The purpose of this installation was: (a) to obtain information about the variation of pore water chemistry with depth by in situ water sampling, and (b) to monitor, by repeated sampling, the variation of pore water chemistry with time at certain installation depths. Since the filter tips were installed in a thick layer of impervious clay, in which it was not likely that the pore water chemistry would vary with time, it was expected that the test series would provide information about the repeatability of the sampling technique. At 16m installation depth, however, seasonal fluctuation of the water chemistry might occur due to influence from the more pervious bottom soil layer.

Pore pressure measurements were carried out concurrent with sampling of pore water. Conductivity tests were also conducted (Figure 12). The results from these tests show that the clay has a coefficient of hydraulic conductivity on the order of 1.5×10^{-10} m/s at all four test elevations.

Figure 7 shows a depth profile of Cl^- concentration at the Verka test location. Sampling of pore water was carried out at 1m-depth intervals. These samples were taken during the installation process of the four permanent filter tips. As shown in Figure 7 the Cl^- concentration in the pore water increases nearly linearly with depth from a value of 15 meq/L at 2 m depth

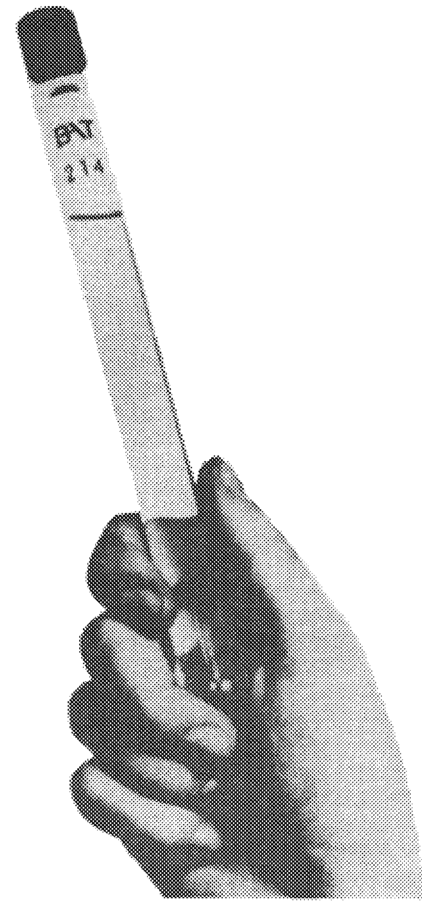

Figure 6. The standard sample container has a volume of 35 ml

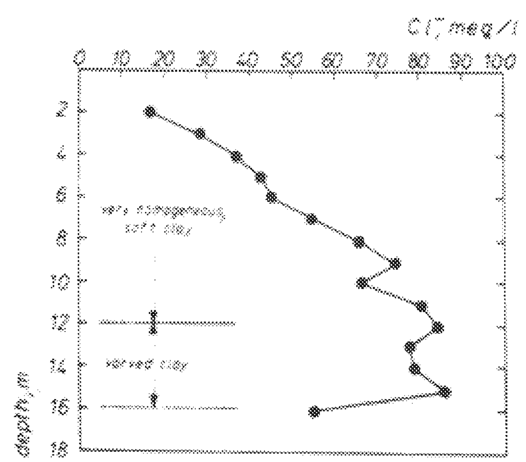

Figure 7. Cl^- —profile at the Verka test site

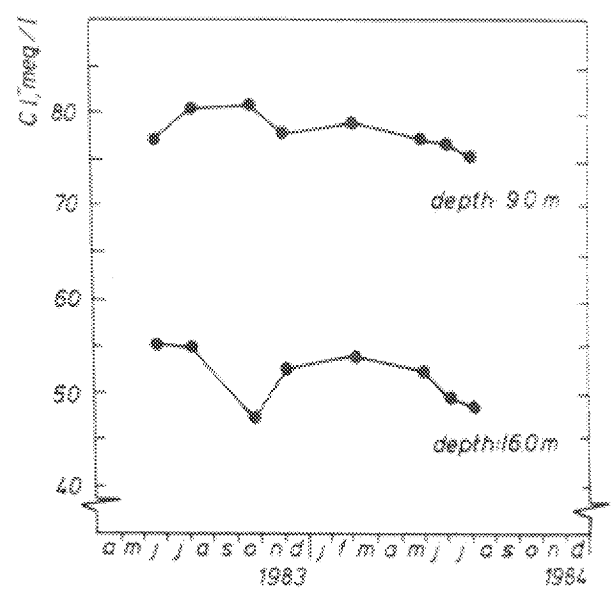

Figure 8. Measured Cl^- —concentration vs. time for pore water samples from 9 and 16m depths at the Verka site

to 85 meq/L at 12m depth. In the depth interval of 12-15m the Cl^- concentration remains fairly constant with an average value of 85 meq/L. At a depth of 16m the Cl^- concentration is reduced to 55 meq/L, indicating an influence on the pore water chemistry from the more pervious bottom soil layer.

The study at the Verka basin has demonstrated that the sampled pore water from the central section clay layer originated from the prehistoric sea in which the clay was deposited some 7,000 years ago.

Figure 8 summarizes the results of repeated pore water sampling at the depths of 9 and 16m. Sampling was performed during a 14-month period. The sampling interval averaged two months.

Figure 8 shows measured Cl^- concentrations vs. time. At a sampling depth of 9m the Cl^- concentration averaged 78 meq/L during the sampling period. As mentioned above, it is unlikely that the pore water chemistry will vary with time at this sampling depth. The maximum measured variation in Cl^- concentration was only 3 meq/L, i.e. about 4 percent of the average value. This result indicates that the sampling technique has an acceptable degree of repeatability.

At 16m sampling depth the Cl^- concentration averaged 52 meq/L. The maximum measured variation in Cl^- concentration was 8 meq/L, i.e. about 15 percent of the average value. This variation is probably due to seasonal fluctuations of the ground water chemistry in the pervious bottom soil layer.

System for in situ measurement of hydraulic conductivity

The system arrangement for in situ measurement of hydraulic conductivity is shown in Figure 9. The measuring system comprises a test adapter that is equipped with a double-sided hypodermic needle and a gas/water container. The pressure in the container is measured with the aid of an electronic pressure transducer.

The test can be carried out either as an "inflow test" or as an "outflow test." In the former case the gas/water container is completely gas-filled at the start of the test. An inflow test can be conducted simultaneously with the extraction of a pore water sample. In an outflow test the container is partly filled with water and partly filled with compressed gas.

The test arrangement for an outflow test can also be used for the controlled injection of a tracer liquid into the soil. The spreading of this liquid can be checked by repeated sampling in filter tips installed at different distances from the point of injection.

It should be noted that the test provides information mainly about the hydraulic conductivity in the horizontal direction. Due to natural stratifications, the horizontal conductivity is often many times greater than the conductivity in the vertical direction.

Test procedures and evaluation of test data

The initial pressure in the gas/water container and the equilibrium pore pressure in the soil is denoted p_0 and p_1, respectively. Before the start of the test the pore pressure p_1 is measured in a conventional manner. The initial pressure p_0, which can be chosen arbitrarily, is easily applied, e.g. with the aid of either a syringe or a pressure regulation valve and a gas bottle.

After preparation, the test adapter is lowered down the extension pipe. Temperature equalization is achieved before connecting the adapter to the filter tip. When the adapter is lowered on the nozzle in the filter tip it is automatically connected to the tip with the aid of the double-sided hypodermic needle. Upon connection of the test adapter to the filter tip the pressure in the gas/water container starts to change. The change in pressure is recorded using the same electronic pressure transducer, mentioned above. Figure 10 shows a typical pressure equalization curve for an inflow test.

The pressure change in the test adapter is quite similar to a falling-head test in a standpipe and can be analyzed by the falling-head theory as defined by Hvorslev (1951). According to Hvorslev the following flow equation applies:

$$q = Fk\,(p_1 - p_0) \tag{1}$$

in which

q = fluid flow (m^3/s)
F = flow factor (m)
k = coefficient of hydraulic conductivity (m/s)
p_1 = equilibrium pore pressure (m H_2O)
p_0 = initial pressure in test adapater (m H_2O)

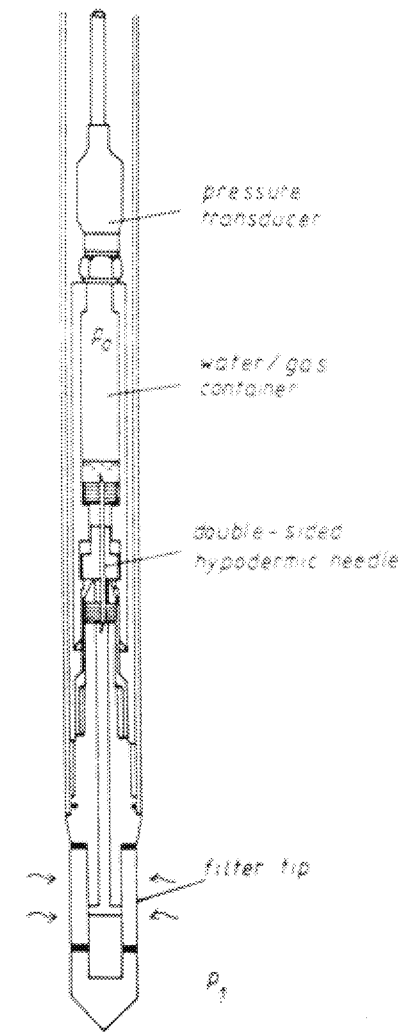

Figure 9. Schematic of the system for in situ measurement of hydraulic conductivity

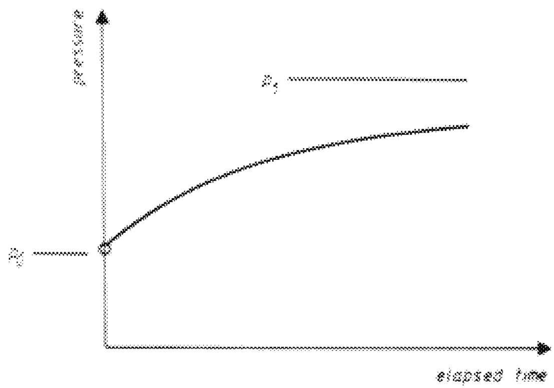

Figure 10. Typical pressure equalization curve for an inflow conductivity test

Hvorslev (1951) further defines the flow factor F as follows:

$$F = \frac{2\pi l}{\ln\left[l/d + \sqrt{1+(l/d)^2}\right]} \qquad (2)$$

in which

l = length of filter (m)
d = diameter of filter (m)

The condition of continuity requires:

$$dV = -q\,dt$$

in which

dV = volume change (m) during time interval dt (s) (3)

The pressure/volume relationship of the gas-filled test container can be defined by Boyle's-Mariotte's law:

$$P_0V_0 = pV \qquad (4)$$

in which

V_0 = initial volume (m^3) in test container
V = volume in test container at time t
p = pressure (absolute)

Boyle's-Mariotte's law is valid for constant temperature. This requirement is normally met for the actual conditions of testing.

By combining Equations 1, 3 and 4 the following expression for the coefficient of hydraulic conductivity k from an inflow test can be derived (Bengtsson 1984):

$$k = \frac{P_0V_0}{Ft}\left(\frac{1}{p_1p_0} - \frac{1}{p_1p_t} + \frac{1}{\frac{2}{p_1}}\left(\ln\frac{p_0-p_1}{p_0} \cdot \frac{p_t}{p_t-p_1}\right)\right) \qquad (5)$$

in which

p_t = pressure in test adapter at time t

(All pressures p in Equation 5 are express in absolute pressures).

The new system can be used for testing in soils having a coefficient of hydraulic conductivity that is less than 1×10^{-6} m/s. The limiting factor is the flow capacity of the hypodermic needle. Figure 11 shows the flow characteristics of the hypodermic needle used in the system.

The BAT apparatus can take several different gas - water containers of differing volume V_0, allowing a wide range of dp/dV values. This permits tests to be carried out with no loss of accuracy even at very low hydraulic gradients. Another important feature of the new system is that conductivity tests can be conducted with constant precision, independent of testing depth.

Comprehensive investigations made by Petsonk (1984) have shown that the system yields surprisingly accurate and consistent values for soil conductivity in a variety of situations.

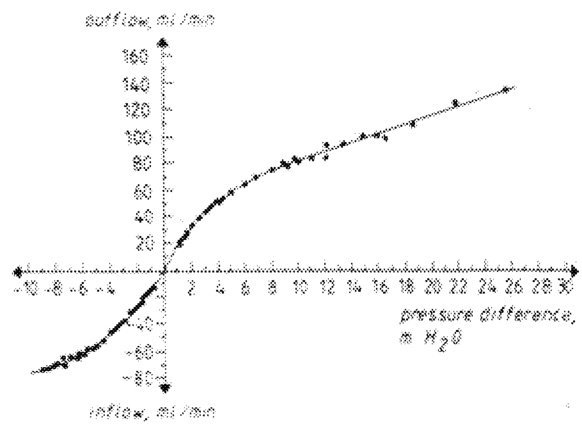

Figure 11. Flow characteristics of the hypodermic needle, used in the system for measurement of hydraulic conductivity

Test results

Figure 12 illustrates a plot of test data for an inflow conductivity test. The actual installation is made in a very soft clay at a depth of 9m below ground surface. The test location is the Verka River basin (Figures 7 and 8).

The test results are plotted in the form of a pressure equalization diagram, i.e. pressure ratio $\ln[(p_1-p_0/p_1-p_t)]$ vs. time. For the actual test the following initial conditions apply:

- Static pore pressure p_1=8.32 m H_2O
- Initial pressure p_0=-2.51 m H_2O
- Volume of gas in container V_0=121.5ml.

In order to study the consistency of the values of the coefficient of hydraulic conductivity as calculated for different testing times, the actual test was run for a period of 2.5 days. Table 1 summarizes values calculated during this test.

Table 1

Calculated values of coefficient of hydraulic conductivity k for different testing times.

Testing time (min)	202	502	1.002	2.002	3.702
Coefficient of hydraulic conductivity $k \times 10^{-10}$ (m/s)	1.53	1.59	1.48	1.49	1.39

Average k value: 1.45×10^{-10} m/s

It can be seen that the calculated values of the coefficient of hydraulic conductivity show only a small variation with length of testing time. The test results suggest that the new system enables tests to be conducted in soils of very low conductivity by using a testing time of only a couple of hours. In soils having a coefficient of hydraulic conductivity within the range of 10^{-6} to 10^{-8} m/s the test can be conducted in only a few minutes.

Figure 12 shows, for sake of comparison, the theoretical pressure equalization curves corresponding to k values of 1.4×10^{-10} and 1.6×10^{-10} m/s, respectively.

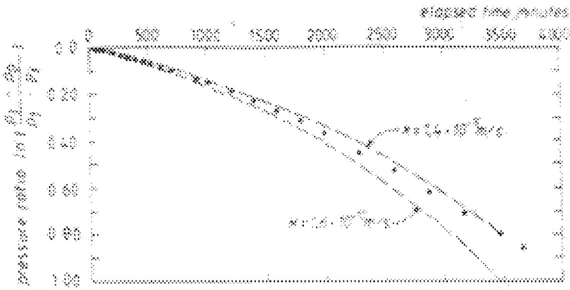

Figure 12. Test data for a longterm in situ test of hydraulic conductivity. Test location: Verka, depth of testing 9.0m

It may be noted, that upon completion of a test of soil conductivity, the results may be controlled by measuring the volume of water that has entered into or flowed out of the gas/water container. Ideally, this volume should correspond to the theoretical volume change as calculated from Equation 4.

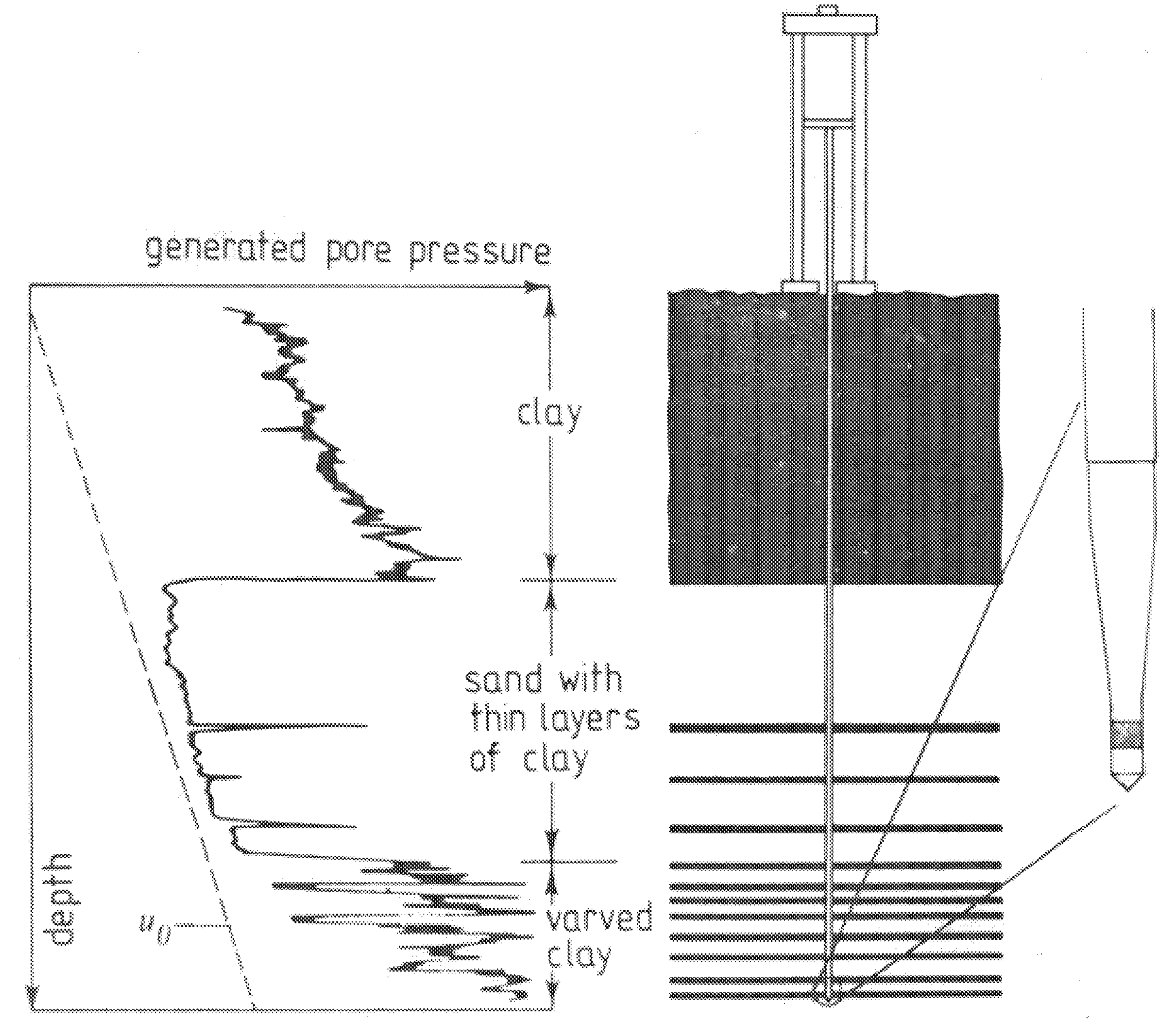

Figure 13. Typical pore pressure sounding diagram for a layered soil. (u_0=equilibrium pore pressure)

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Installation of Filter Tips

Finally, it is appropriate to discuss installation techniques for filter tips. When filter tips are installed for the purpose of ground water monitoring it is important to consider the stratification of the actual deposit. For example, if the soil profile contains permeable layers embedded in impermeable soil, these layers may be critical for the spread of pollutants in the ground water.

The pore pressure probe, (Torstensson 1975 and 1977), is a tool that provides detailed information about the stratification of soft, saturated soils. It is especially suited for the indentification of permeable layers in cohesive soil. This system utilizes the pore pressures that are generated when a conical filter tip penetrates the soil at a constant speed (Figure 13). The generated pore pressure is primarily a function of the hydraulic conductivity of the soil layers. In normally consolidated clays, high excess pore pressures are generated. In more permeable soils, such as sand and silt, penetration of the pore pressure probe normally generates only small excess pore pressures. The probe has an extremely rapid response to changes in pore water pressure. Thus, embedded seams of sand or silt in clay are distinctly shown as sudden pressure drops on the pore pressure/depth diagram. On the other hand, thin clay layers embedded in sand are shown as sudden pressure peaks. Figure 13 shows an idealized pore pressure sounding diagram for a layered soil.

Compared with the traditional method of measuring the cone penetration resistance, the pore-pressure probe is a much more sensitive tool for registration of the stratification of a saturated, soft soil deposit.

Prior to the installation of permanent filter tips for ground water monitoring, the pore pressure probe can provide useful information for the selection of relevant installation depths.

The permanent filter tip is normally installed by pushing it down to the desired depth. During installation it is very useful to utilize the filter tip itself as a pore-pressure probe. Using this procedure it is possible to install the filter tip exactly in a pre-selected soil layer. By choosing a suitable filter height, the filter tip can, for example, be installed in embedded permeable layers with a thickness of not more than 5-10mm.

Acknowledgment

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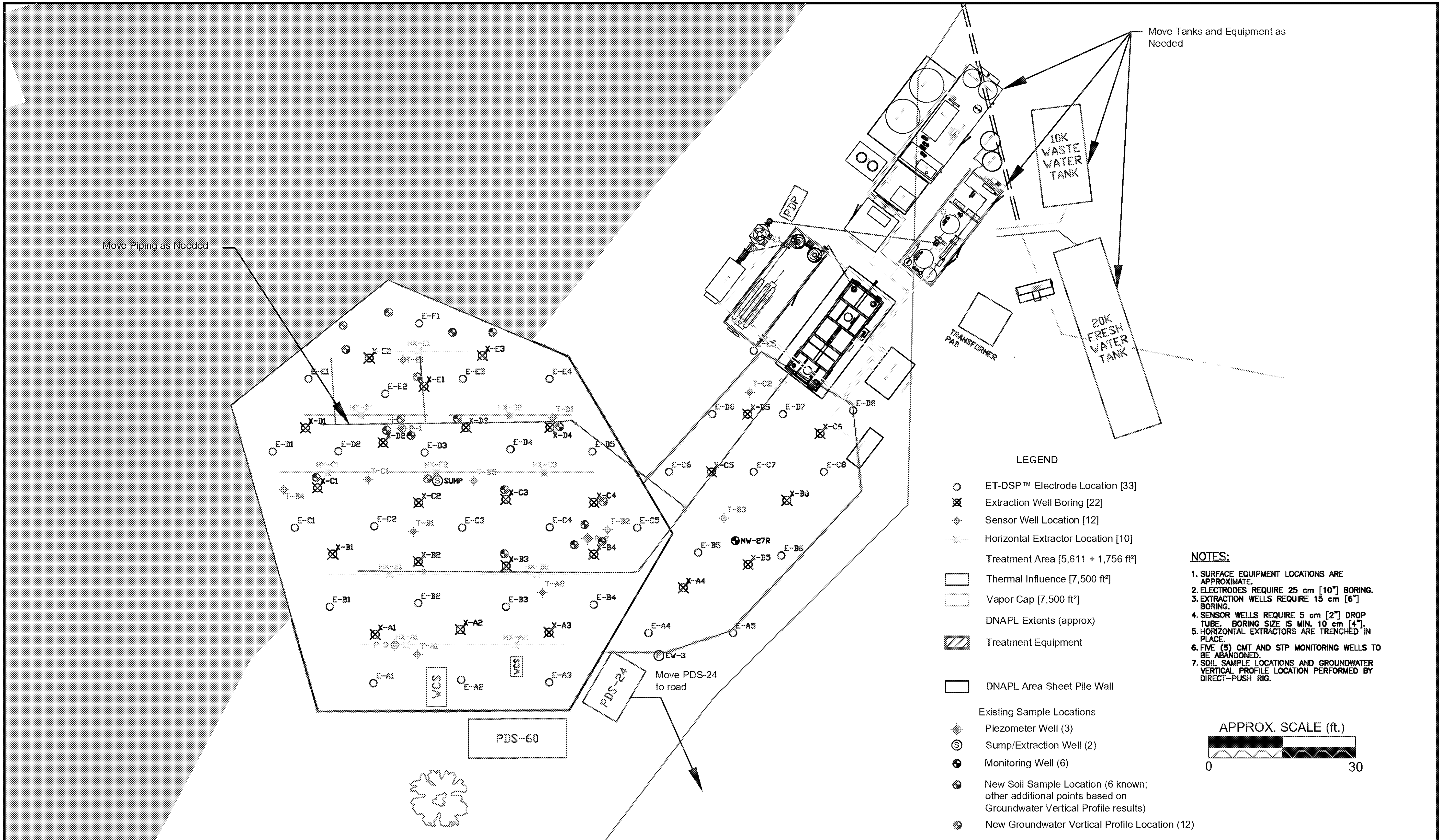
Biographical Sketch

Bengt-Arne Torstensson (BAT Envitech AB, P.O. Box 27194, S-102 52 Stockholm, Sweden; U.S. Office: BAT Envitech Inc, 3777 Long Beach Blvd, Long Beach, CA 90807 PH: (213) 427-6824.) received M.Sc. degree in civil engineering from Chalmers University of Technolgy, Sweden, in 1965. He obtained a Ph.D. in soil mechanics and foundation engineering from Chalmers University in 1973. He is the president of BAT Envitech AB, a company that specializes in environmental engineering and development and manufacture of related field instrumentation.

Appendix B

1. Figure PSL-01, Proposed Sampling Locations.



LEGEND

- ET-DSP™ Electrode Location [33]
- Extraction Well Boring [22]
- Sensor Well Location [12]
- Horizontal Extractor Location [10]
- Treatment Area [5,611 + 1,756 ft²]
- Thermal Influence [7,500 ft²]
- Vapor Cap [7,500 ft²]
- DNAPL Extents (approx)
- Treatment Equipment
- DNAPL Area Sheet Pile Wall

Existing Sample Locations

- Piezometer Well (3)
- Sump/Extraction Well (2)
- Monitoring Well (6)
- New Soil Sample Location (6 known; other additional points based on Groundwater Vertical Profile results)
- New Groundwater Vertical Profile Location (12)

NOTES:

1. SURFACE EQUIPMENT LOCATIONS ARE APPROXIMATE.
2. ELECTRODES REQUIRE 25 cm [10"] BORING.
3. EXTRACTION WELLS REQUIRE 15 cm [6"] BORING.
4. SENSOR WELLS REQUIRE 5 cm [2"] DROP TUBE. BORING SIZE IS MIN. 10 cm [4"].
5. HORIZONTAL EXTRACTORS ARE TRENCHED IN PLACE.
6. FIVE (5) CMT AND STP MONITORING WELLS TO BE ABANDONED.
7. SOIL SAMPLE LOCATIONS AND GROUNDWATER VERTICAL PROFILE LOCATION PERFORMED BY DIRECT-PUSH RIG.

APPROX. SCALE (ft.)
0 30

McMILLAN-McGEE CORP.
CREATORS OF ET-DSP™

McMILLAN-McGEE CORP.
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REV.	DATE (Yr/MO)	DESCRIPTION	DRAWN BY	ORG/ ENGR	Aproved Dist
A1	2019/11/28	FOR REVIEW AND COMMENT	DAR	DAR	DAR

DRAWING NUMBER: | SCALE: NOT TO SCALE

TITLE: **Proposed Sample Locations**

CLIENT: **Third Site Trust Fund**
Third Site ERH
Zionsville, Indiana

SHEET: **PSL-01**

Appendix C

1. *Job Safety Analysis, Hot Soil Sampling*, McMillan-McGee Corporation, 2015.

JOB SAFETY ANALYSIS

MCMILLAN-MCGEE CORP	**Project:**	Third Site	
	Job:	Hot Soil Sampling	
	Risk:	Significant Risk Task	

Revision No. JSA-Mc2-HSS-2015-10	JSA Type: Hot sampling
Revision Date: October 20, 2015	Task Type: Hot soil sampling on ET-DSP™ projects
Approved Date:	Affected Position: ET-DSP™ operator, drilling and sampling personnel

PPE	**Personal Protective Equipment**	
Type	Personal Protective Equipment	Description
Head Protection	Hard hat	Type I, Class E, compatible with face shield, ANSI Z89.1-2003 / CSA Z94.1-15
	Face shield	For splash protection when there is a risk of exposure to hot fluids
Foot Protection	Steel-toed boots	Electrical hazard (EH) rated, Grade 1, ANSI Z41.1-1999 / CSA Z195-14
Dermal Protection	Long sleeve shirt and pants	For protection against thermal exposure; coveralls can also be used
	Rain coat	For splash protection when there is a risk of exposure to hot fluids
	Saranex suit	Required in well field when there is risk of chemical exposure.
Eye Protection	Safety glasses or safety goggles	With side shields, ANSI Z87.1-2010 / CSA Z94.3-07
Hand Protection	Electrical insulated gloves	Class 0, with outer leather protectors, 29 CFR 1910.137
	Thermal resistant gloves	Heavy-duty leather or rubber insulating
	Nitrile gloves	Required beneath outer gloves when there is risk of chemical exposure
Worker Visibility	High visibility safety vest	Class II or greater, ANSI 107-2015 / CSA Z96-15

Supplies		
Type	Supply	Description
Sampling	Waste disposal drum	Correctly identified and labeled for management of wastes
	Core barrel with SS or PTFE sleeve	Drilling contractor to supply materials for direct push sampling, including end caps
	Decontamination supplies	Drilling contractor to perform decontamination of downhole equipment
Communication	Mobile phone	
Tools	Electrically isolated tools	Wrenches, pliers, ratchets, sockets, screwdrivers, drills, impact drivers, etc.
Miscellaneous	Volt meter	Stray voltage eliminator must be used on digital meters
	Step and touch testing apparatus	
	Photoionization detector (PID)	Calibration to be performed prior to use
	Temperature gun	
	Thermometer	
	Ice bath	
	Eye wash supplies	Refer to site health and safety plan

Warnings		
Type	Special Precautions	Action Requirement
Lightning	Electrocution	No one is permitted in the well field during lightning and until 30 minutes after the last recorded strike.
Hot Fluids and Surfaces	Third degree burns	Equipment only to be handled when temperatures are equal to or less than 50°C/122°F, or with appropriate PPE up to temperatures of 120°C/248°F.
Energized Well Field	Electrocution	Prior to performing the task, all electrodes near the work area must be shut off and step and touch potential testing must be performed. Use electrically isolated tools.
Contamination	Chemical exposure	Review site-specific health and safety plan and consult with onsite health and safety representative to determine air monitoring protocols, MSDS, PPE requirements, and engineering controls to mitigate risk of exposure.

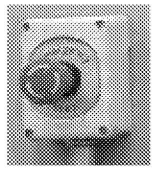
Job Steps

Job Step No.	Job Step Description		Potential Hazard	Critical Action	Reference
1	Preparation and mobilization	1	General operations hazards	• Review general site operations and maintenance plan (O&M Plan). • Review site health and safety plan (HASP). • Review waste management procedures to control all waste being generated during sampling and decontamination procedures. • Review Lead Engineering Consultant's associated JSAs. • Review relevant McMillan-McGee JSAs: i. PDS Shut-Down and Start-Up. ii. Electrode Shut-Down and Start-Up. iii. Energize/De-Energize Breakers. iv. Single-Source Lockout-Tagout (LOTO). v. Step and Touch Potential Testing. • Review Drilling Contractor's associated JSAs. i. Mobilization. ii. Direct Push Rig Operation. iii. Skid Steer / Compact Loader Operation. iv. Demobilization. • Review general site activities. • Plan route for personnel and equipment, making sure not to block the area in the event of an emergency evacuation. • Perform rig and equipment daily inspection.	• HASP • O&M Plan • Associated JSAs
		2	Slips/trips/falls	• Inspect and familiarize self with work area; remove or mark potential tripping/slipping hazards that may be present in the work area. • Use care when stepping over or around cables, wires, pipes and hoses.	
		3	Inclement weather condition - cold stress (winter) and heat stress/sun burns (summer)	• For colder weather, wear extra layers of warm, loose clothes, hat and scarf to cover face, ear and neck, have cold-prevention liners worn under typical nitrile, work or insulating gloves. • For hotter weather, consume enough water to stay hydrated, plan work/rest shifts, and apply sun screen to prevent sun burn.	
		4	Damaged tools	• Gather and inspect tools prior to work.	
		5	Damaged PPE	• Gather and inspect PPE prior to work. • Eyewash station can freeze in cold conditions.	
2	De-energize electrodes	1	Exposure to hot vapors	• Consult with a McMillan-McGee representative at least 24 hours prior to scheduled drilling and sampling activities, in order to determine the time needed for the electrodes to be shut down to cease steam production in the subsurface.	
3	Calibrate air monitoring equipment	1	Exposure to calibration gas	• Review relevant equipment manuals for safe calibration procedure and perform in a clean, well ventilated area.	• PID equipment manual

JOB SAFETY ANALYSIS

Project:	Third Site	*Page: 3 of 9*
Job:	Hot Soil Sampling	
Risk:	Significant Risk Task	

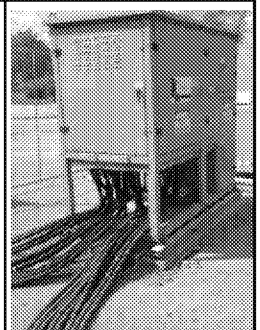
Job Steps

Job Step No.	Job Step Description		Potential Hazard	Critical Action	Reference
4	Turn off relevant ET-DSP™ equipment and place under LOTO	1	Emergency Shutdown Device (ESD)	• Review emergency shutdown device locations specific to treatment volumes where sampling activities will take place. • Consult with a McMillan-McGee representative to determine if it is necessary to activate the ESD prior to entering well field.	
		2	Electrocution from hazard from energized equipment	• Determine if ET-DSP™ system is ON or OFF. View the ET-DSP™ beacon lights located above the Power Delivery Systems (PDS): i. ON = Beacon lights will be flashing ORANGE. The ET-DSP™ electrodes have the ***potential*** to be energized. Note that the beacon lights may flash whether or not the electrodes are energized. ii. OFF = ORANGE beacon lights are off. The ET-DSP™ electrodes are de-energized. Note that power is still being supplied to the PDS units – PDS units are energized. • Activate the ESD button if the McMillan-McGee representative has suggested doing so. The orange beacon lights above the associated PDS units should now be OFF. • Have the ET-DSP™ operator place the secondary of the PDS units upstream of the electrodes in the treatment area under LOTO. • Don appropriate PPE for step and touch potential testing. • Have the ET-DSP™ operator to perform step and touch potential tests on wells and piping within vicinity of soil sampling locations prior to allowing personnel into the well field perimeter. • If potentials are higher than 15 V in the vicinity of soil sampling locations, notify a McMillan-McGee representative and wait for guidance.	• JSA: PDS Shut-Down and Start-Up. • JSA: Electrode Shut-Down and Start-Up. • JSA: Energize/De-Energize Breakers • JSA: Single Source Lockout-Tagout (LOTO) • JSA: Step & Touch Potential Testing 
5	Mobilize direct push drill rig to sampling location	1	General operations hazards	• Review Drilling Contractor's associated JSAs. • Don appropriate PPE for rig mobilization. • Be aware of rig operation and movements during all phases of sampling activities. Plan the path that the rig will travel prior to setting up on sampling location(s). If the rig needs to be craned into well field, develop a lift plan. • Perform visual check for any safety concerns: high voltage lines, uneven terrain, aboveground and underground utilities and egress limitations with rig placement. i. H-20 rated wire bumper or ramps are to be used where the rig is intended to drive over electrical cables or hoses. ii. Spotter must be utilized when the rig is egressing/digressing from the well field. • Assess compressive strength of vapor cap prior to rig mobilization; use rig mats or plywood sheets to disperse weight if needed. • Communicate project requirements to the operator and support staff prior to	• Drilling contractor JSAs • Lift plan, if needed

JOB SAFETY ANALYSIS

Project:	Third Site	
Job:	Hot Soil Sampling	
Risk:	Significant Risk Task	

Job Steps

Job Step No.	Job Step Description		Potential Hazard	Critical Action	Reference
				commencing sampling activities. • Position rig downwind of sample location so as the crew and samplers can be positioned upwind if possible.	
		2	Encountering underground or overhead utilities	• Have all utilities located prior to drilling. • Hand auger or air knife first 5 ft of the boring to clear location for potential buried utilities. • If risk of heat or chemical exposure is suspected, don appropriate PPE (see Job Step No. 6). • Review additional subsurface clearance conditions specific to the project.	• Site Health and Safety Plan • See Job Step No. 6
		3	Electrocution from hazard from energized equipment	• All Teck cables (black, armored cable) are energized; keep all equipment a minimum of 10 ft away from Teck cables at all times. • If unable to maintain at least 10 ft of clearance, based on how equipment must maneuver, consult with a McMillan-McGee representative to coordinate de-energizing Teck cables at the Power Distribution Panel (PDP) and placing them under LOTO. • Keep all equipment a minimum of 10 ft or greater from all other overhead or subsurface electrical lines, depending on voltage.	
6	Assess heat and chemical exposure hazards, don appropriate PPE	1	Exposure to hot surfaces, hot vapors and contaminants	• Perform a walk down in the vicinity of the sampling locations to ensure that there is no evidence of steam or hot vapor emissions. • Monitor and document breathing space. • Don thermal PPE (long sleeve shirt/pants, rubber thermally-insulating gloves) and splash PPE (face shield, and raincoat) when working in the vicinity of the drill rig, treating all pipes, hoses and downhole equipment as hot. i. There should be no exposed skin after donning PPE. ii. Use temperature gun to verify surface temperatures prior to doffing thermal PPE. • Surface temperatures above 50°C/122°F will burn exposed skin – avoid contact. • If risk of exposure to contaminants is suspected, don contaminant PPE (e.g., Saranex suit, nitrile gloves), in consultation with the health and safety officer.	• HASP • Site Health and Safety Officer
7	Collect and process direct push soil sample(s)	1	General operations hazards	• Review Drilling Contractor's associated JSAs. • Advance push sampler to required depth and collect samples using PTFE, stainless steel or brass sleeves inside core barrel for temperature compatibility. • Withdraw the core barrel slowly (e.g., 2 ft/min) to allow subsurface pressures to equilibrate. Depressurization can lower the boiling point of groundwater and produce hot vapors. • Splash PPE (face shield, rain coat) may be	• Drilling contractor JSAs

Job Steps

Job Step No.	Job Step Description		Potential Hazard	Critical Action	Reference
				doffed when invasive activities are complete and all equipment has been removed from downhole.	
		2	Hot soil handling/cooling	• Using temperature gun make sure core barrel does not exceed 50°C/122°F. • Disassemble the core barrel, ensuring that rubber thermally-insulating gloves are worn over the nitrile gloves. Remove the sample sleeves as the core barrel is disassembled. • Cap sample sleeves immediately at each end following collection. PTFE tape can be used to improve the seal if needed. • Place the sealed sample into an ice bath. Water from melting ice should be allowed to drain and sleeves should not be submerged. • Cool sleeves until soil nears ambient temperature (approximately 20°C/70°F). Use a standard thermometer inserted through the end cap to monitor soil temperature.	• Attachments
			Sample processing / cutting hazard	• Once near-ambient temperature, the soil can be sampled using standard sampling and labeling methods. • PTFE sample sleeves may be placed in a vise, cut lengthwise and sampled in the field. Care must be taken when a blade is used to perform cuts, and blades must be decontaminated between uses. • Soil can be extruded from stainless steel or brass sample sleeves in the field, or sent to the laboratory for analysis.	• Site Sampling Plan
		3	Exposure to contaminants	• Work in a ventilated area upwind of samples. • Perform air monitoring in breathing zone. • Don chemical resistant PPE or implement engineering controls as appropriate to mitigate exposure in accordance with the health and safety plan.	• HASP
		4	Exposure to soil preservatives	• Work in a ventilated area upwind of samples. • Monitor and document breathing zone. • Review site health and safety plan.	• HASP
		5	Infectious water-borne diseases	• Review site health and safety plan.	• HASP
		6	Electrocution	• Review site health and safety plan. • A Ground Fault Circuit Interrupter (GFCI) device must be used to protect relevant alternating current (AC) circuits. • Ensure the equipment is correctly grounded. • Do not stand in wet areas while operating electrical equipment, and ensure cords do not come into contact with water.	• HASP
		7	Repetitive motion and ergonomic Issues	• Review site health and safety plan. • Use safe lifting techniques and mechanical means where possible when sampling.	• HASP
		8	Slips/trips/falls	• Review site health and safety plan.	• HASP

Job Steps

Job Step No.	Job Step Description		Potential Hazard	Critical Action	Reference
				• Ground may become wet or muddy. • Place all purged water in drums for removal. • Ensure foot ware is slip-resistant.	
8	Decontaminate downhole and sampling equipment	1	Exposure to contaminants	• Decontaminate all downhole and sampling equipment in accordance with health and safety plan and/or drilling contractor JSAs. • Decontamination to occur prior to each use, between sampling locations, after all locations have been completed. • If not specified in the health and safety plan, decontamination to consist of: i. Removal of contamination from all sampling equipment using steam cleaning or other appropriate methods. ii. Cleaning with brushes using a biodegradable soap and water mixture. iii. Rinsing with distilled water.	• HASP • Drilling contractor JSAs • Review waste management procedures to control all waste being generated during the decontamination procedure
9	Abandon direct push sampling location	1	General operations hazards	• Review Drilling Contractor's associated JSAs.	• Drilling contractor JSAs
		2	Inhalation of fines	• Review applicable Material Data Safety Sheets (MSDSs) for abandonment materials in accordance with health and safety plan.	• HASP • Drilling contractor JSAs
		3	Exposure	• Grout must be slowly pour or pumped into sample location, as steam and chemicals may be displaced during installation. • Don thermal PPE (long sleeve shirt/pants, rubber thermally-insulating gloves) and splash PPE (face shield, and raincoat) when working in the vicinity of the drill rig, treating all pipes, hoses and downhole equipment as hot. i. There should be no exposed skin after donning PPE.	• HASP • Drilling contractor JSAs
10	Demobilize direct push drill rig from sampling location	1	General operations hazards	• Review Drilling Contractor's associated JSAs. • Don appropriate PPE for rig demobilization. • Be aware of rig operation and movements during all phases of sampling activities. Plan the path that the rig will travel prior to demobilization. If the rig needs to be lifted out of the out of the well field via a crane, develop a lift plan. • Spotter must be used when moving the rig. • Perform visual check for any safety concerns: high voltage lines, uneven terrain, aboveground and underground utilities and egress limitations with rig placement.	• Drilling contractor JSAs • Lift plan, if needed
		2	Encountering underground or overhead utilities	• Have all utilities located prior to drilling. • Keep all equipment a minimum of 10 ft or greater from all other overhead or subsurface electrical lines, depending on voltage. • Teck cables may be energized; keep all equipment a minimum of 10 ft away from Teck cables at all times.	
11	Start up the ET-DSP™	1	General operations	• Ensure all equipment has been removed from	• JSA: PDS Shut-Down

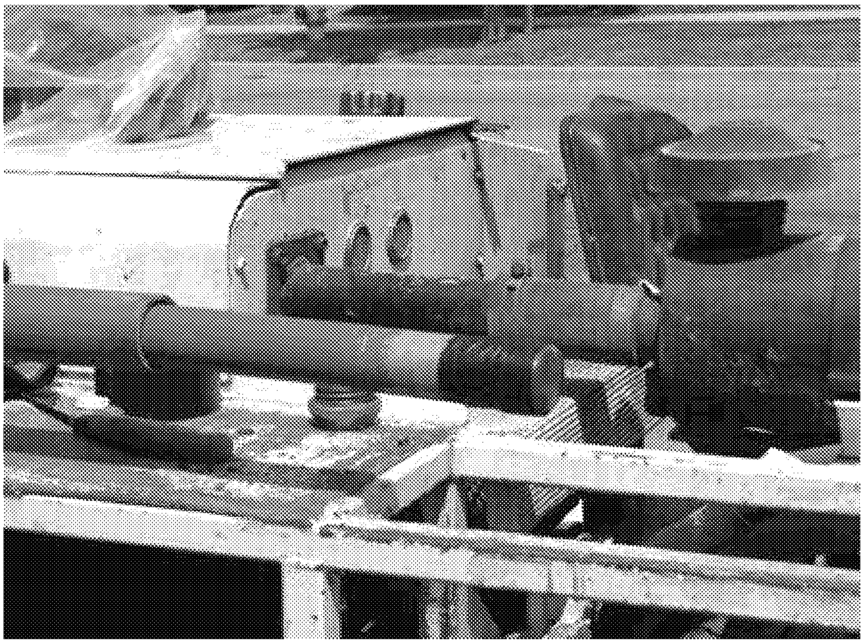
Job Steps

Job Step No.	Job Step Description		Potential Hazard	Critical Action	Reference
	system		hazards	and all personnel have exited the electrode well field perimeter. • Have the ET-DSP™ operator remove components from LOTO, deactivate the ESD, energize the PDS units, and follow startup procedures as per McMillan-McGee's associated JSAs.	and Start-Up. • JSA: Electrode Shut-Down and Start-Up. • JSA: Energize/De-Energize Breakers • JSA: Single Source Lockout-Tagout (LOTO) • JSA: Step & Touch Potential Testing

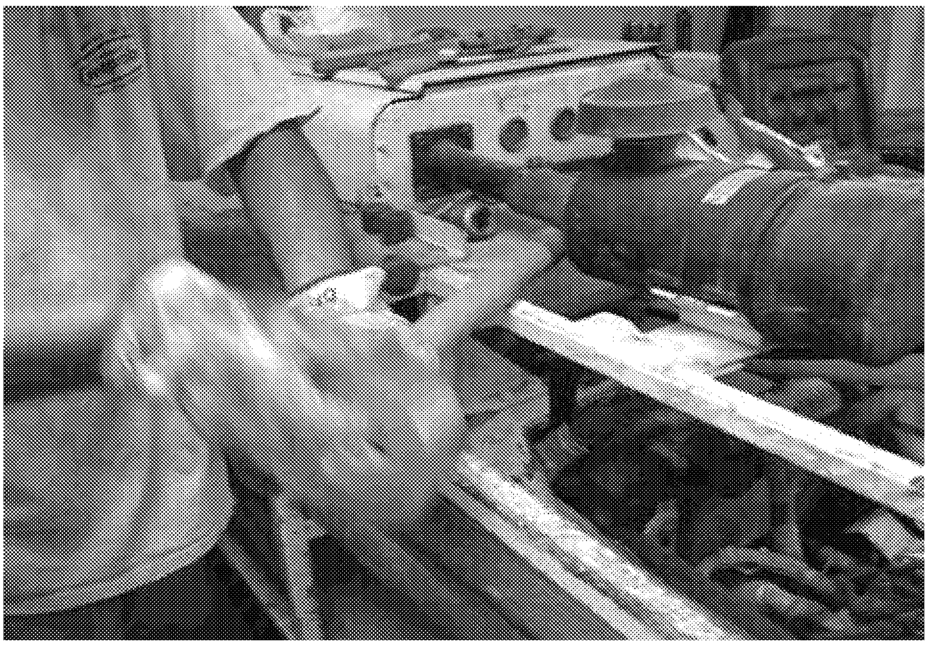
Attachments

Photographs of Sampling Procedure

Attachments



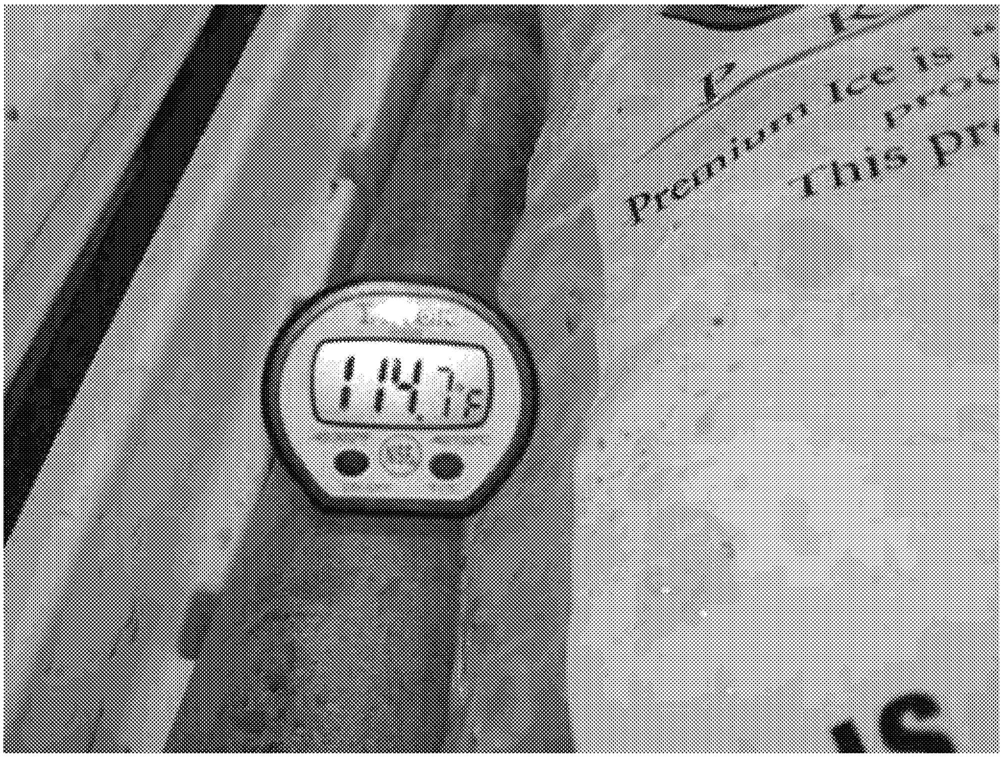
PTFE sleeve capped and taped shut



Taping a cap onto the PTFE sleeve

JOB SAFETY ANALYSIS

McMILLAN-McGEE CORP	**Project:**	Third Site — *Page: 9 of 9*
	Job:	Hot Soil Sampling
	Risk:	Significant Risk Task



Sample temperature prior to ice bath

Sample temperature after ice bath